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# TIMING OF FACIAL GROWTH IN AUSTRALIAN ABORIGINES

## A study of relations with stature and ossification in the hand around puberty

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## PREFACE

The adolescent growth spurt is a constant phenomenon occurring in all children, but varying in time of onset, in intensity and duration from one child to the next. The chronological age of a child, therefore, is a poor indicator of physiological status.

An understanding of the relation between the timing of maximum growth in the facial skeleton and other maturation events is useful in the planning of orthodontic treatment. Moreover, reliable methods of estimating the timing of maximum skeletal growth would be of clinical value in fields apart from orthodontics.

The purpose of this investigation is to ascertain:

1. The timing of skeletal maturation events as observed on standardized hand and wrist roentgenograms;
2. The timing of maximum growth in body height;
3. The timing of maximum growth of selected craniofacial components;
4. The relation between the timing of maturation events, maximum growth in body height and maximum facial growth, during the circumpuberal period;
5. The most reliable and clinically useful predictors of maximum craniofacial growth.

## SUMMARY

The main objective of the investigation was to ascertain the relations between the timing of maturation events, maximum growth in body height and maximum facial growth, during the circumpuberal period in Aboriginal children.

Longitudinal records of subjects enrolled in a University of Adelaide Growth Study are filed in the Department of Dental Science. Records of 52 males and 36 females were selected from those available to provide suitable observations for the study. Most of the subjects belonged to the Wailbri tribe of Australian Aborigines living under settlement conditions at Yuendumu in the Northern Territory of Australia.

Variables studied included the magnitude and timing of peak growth velocity in body height obtained from serial observations of stature made at Yuendumu; the time of ossification of the pisiform, hook of the hamate-stages 1 and 2 and sesamoid bones obtained from serial hand and wrist roentgenograms; and, finally, the magnitude and timing of peak growth velocity in facial dimensions obtained from serial lateral head roentgenograms.

A preliminary study was made to determine the most suitable method for skeletal age assessment and to select carpal ossification events for analysis. Facial dimensions were selected to cover most aspects of the nasomaxillary complex. A series of double determinations were made in order to determine the magnitude of experimental errors and the extent to which they affected results.

The times of appearance of carpal ossification events and the times of peak growth velocity in stature and facial dimensions were recorded as the mid-point of the year during which the events occurred.

The relations between carpal ossification and peak growth velocity in stature and the facial skeleton were studied. Coefficients of linear correlation between paired variables were determined as well as time intervals between paired events.

Results showed that Aborigines and Caucasoids were similar in their patterns of carpal maturation and general body and facial growth. Sex differences were shown to occur in the time of appearance of carpal ossification events, and in the magnitude and timing of peak growth velocity in stature and the facial skeleton. In addition, it was noted that there was a sex difference in the relation between the timing and sequence of peak growth velocity in facial dimensions,and stature. For example, in females, peak growth velocity of most facial dimensions occurred after peak growth in stature, while in males peak growth velocity of most facial dimensions occurred either before or coincident with peak growth velocity in stature.

All carpal ossification events ossified before peak growth velocity in stature and facial dimensions. In general, carpal ossification was found to be a fairly reliable indicator of the growth rate. In particular, the pisiform (in females) and hamate-stage 1 (in males) were found to be closely related to the onset of peak growth velocity because each event ossified on the average, approximately 1.5 years before peak growth velocity in stature. Hamate-stage 2 and sesamoid ossification indicated that peak growth velocity had occurred or was imminent because each event ossified on the average, 0.4 years before peak growth velocity in stature.

The investigation clarified the understanding of general relations between body growth, skeletal maturation and facial growth. In particular, the results can be applied in orthodontic practice as a means of assessing the growth status of children.

ACKNOWLEDGEMENTS

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Professor A.A. Abbie made available a series of hand and wrist roentgenograms obtained on field trips to Yuendumu. Computer programmes used in the research were coded by Dr. T. Brown.

I am extremely grateful to Professor A.M. Horsnell, Head of the Department of Dental Science and Professor J.C. Thonard, Dean of the Faculty of Dental Science for making available the facilities of the Department.

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## SIGNED STATEMENT

This thesis is submitted in final fulfilment for the requirements of the Degree of Master of Dental Surgery in The University of Adelaide. Entry to candidature for the Degree was gained by passing a Qualifying Examination in November, 1969 of a standard equivalent to the Honours Degree of Bachelor of Dental Surgery. Study for this examination was in the field of Dento-facial Growth and Development.

The thesis contains no material which has been accepted for the award of any other degree or diploma in any University. To the best of my knowledge and belief, it contains no material previously published or written by another person, except when due reference is made in the text of the thesis.

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CHAPTER I

# INTRODUCTION: SKELETAL MATURATION AND FACIAL GROWTH

## SKELETAL MATURATION

SCAMMON ('27) stated that Count Philibert Gueneau de Montbeillard was responsible for the first recorded longitudinal growth study. A velocity growth curve of his son (Fig. 1) illustrates a typical pattern of growth in height, velocity decreasing from birth onwards except for one or possibly two periods when an increase is observed. The earlier period has been called the juvenile growth spurt, occurring between 6 - 8 years, while the second period, the adolescent growth spurt, occurs between 13 - 15 years.

BOAS ('32) found that the adolescent growth spurt occurred approximately two years earlier in girls than in boys. Furthermore, TANNER ('62) stated that the maximum rate of growth is found just before or during puberty.

Four systems are commonly used to determine physiological maturity. They include: skeletal age, dental age, morphological age and secondary sex character age. Skeletal age is discussed separately later in this Chapter.

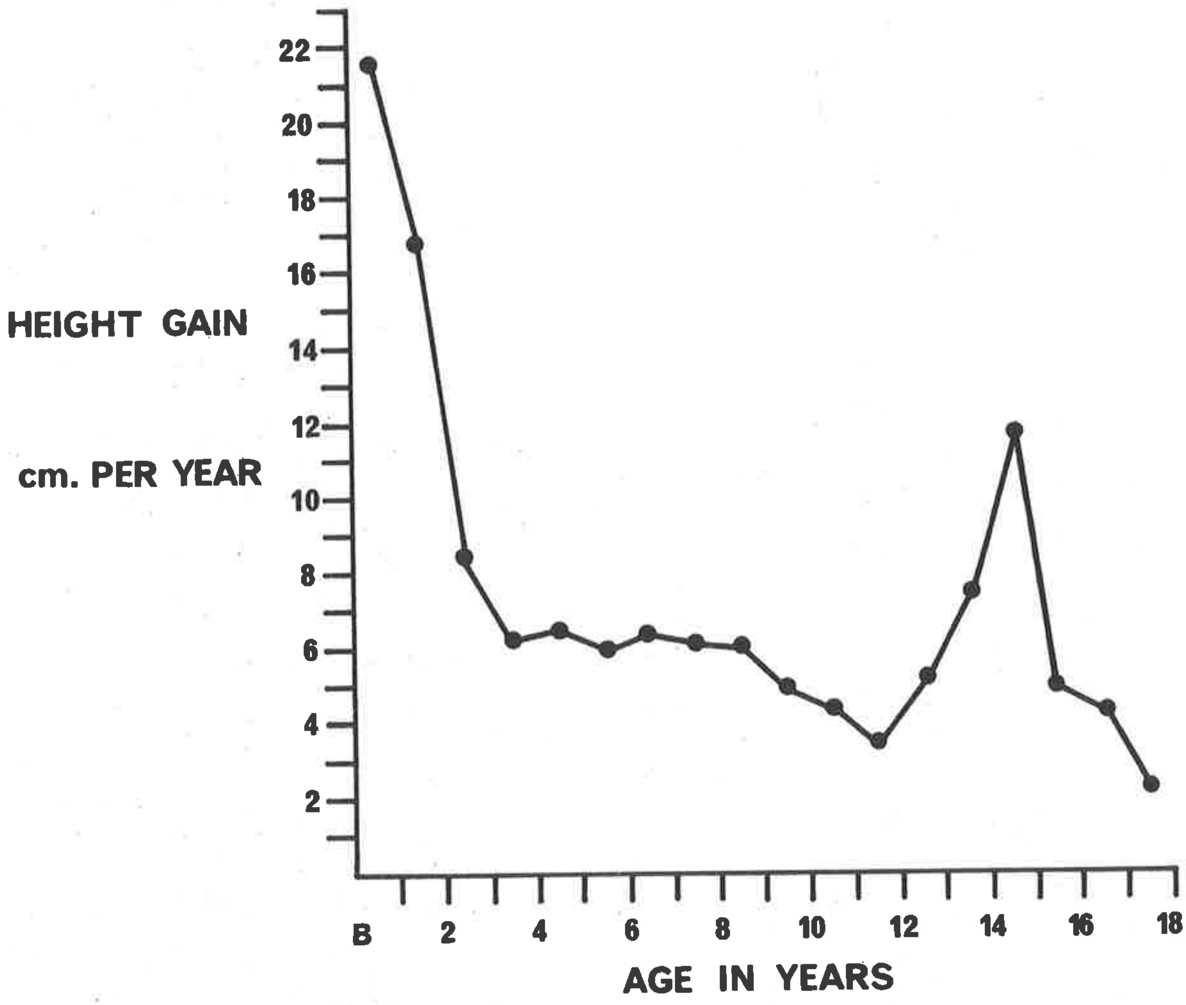


Fig. 1. Velocity curve of increments in height of de Montbeillard's son from birth to 18 years. (Data from Tanner '62).

## DENTAL AGE

Tooth eruption and tooth development patterns have been employed to assess the physiological status of children.

CLEMENTS, DAVIES-THOMAS and PICKETT ('53) noted that early eruption of the second molar was related to early puberty. SUTOW, TERASAKI and OHWADA ('54) compared skeletal development with dental status in 1,360 Japanese children aged 6 - 14 years. Assessment of dental status was made by counting the number of erupted teeth. They found that children advanced in skeletal development had a greater number of erupted teeth than children below average skeletal development. However, STEEL ('64) found that at 12 years of age, there was no simple direct relation between dental and skeletal maturity.

BJÖRK and HELM ('67) studied the relation between the timing of two definite stages of tooth eruption and maximum growth in body height. They concluded that dental development was of little value as a criterion of puberty.

LAMONS and GRAY ('58) determined dental age from a tooth developmental chart (SCHOUR and MASSLER, '41) and made comparisons with skeletal and chronological age. They found chronological age was a slightly better index of tooth development than skeletal age which varied independently of dental age.

LAUTERSTEIN ('61) found high positive correlations between the root of the lower right first permanent molar and skeletal age and between root development and the number of erupted permanent teeth.

LEWIS and GARN ('60) studied the relation between tooth formation and a number of maturation events. They reported that during infancy and childhood, correlations between tooth formation and general growth and development were low and rarely significant. However, as adolescence approaches, correlations between the same variables increased.

MOORREES, FANNING and HUNT ('63) presented sex-specific standards for dental age assessment. In addition, means and standard deviations were listed for developmental stages of crowns and roots of the permanent mandibular canine, premolars and molars (FANNING and BROWN, '71).

## MORPHOLOGICAL AGE (SIZE AND SHAPE AGE)

Size and shape of individuals have been used as a measure of development. SHELDON ('40) popularized the classification of body build into three main somatotypes: endomorphy, mesomorphy and ectomorphy. Subjects were photographed standing nude in front of a calibrated grill and certain anthropometric measurements were made. From a numerical scale, a classification was made. Somatotype ratings have been related to physiologic status by a number of workers including DUPERTUIS and MICHAEL ('53), ACHESON and DUPERTUIS ('57) and HUNT, COOKE and GALLAGHER ('58).

WETZEL ('41, '43) introduced the 'Wetzel Grid' as a means of assessing growth in children in relation to illness and malnutrition. The grid was constructed so that it was possible to determine quantitative ratings on such attributes as physique, developmental level, basal metabolism and calorie needs from stature, weight, sex and age data.

MEDAWAR ('44) designed a grid to illustrate the change in vertical proportions of the body from five months to adulthood. An equation expressed the change in relation of defined anatomical levels with increasing age, and from this a shape age was developed.

## SECONDARY SEX CHARACTER AGE

The onset of puberty is usually assessed from the appearance of outward signs attributable to the action of sex hormones. Puberty is considered to begin when pubic, axillary or facial hair appear, when the testes, penis or prostate begin to increase in size or when breast development is noticeable. BURSTONE ('63) considered that in most children marked secondary sex characteristics appeared later than the peak velocity of growth in height.

Menarche nearly always occurs after the apex of the height spurt has passed (DEMING, '57). GREULICH ('38) commented *"the marked irregularity of the early menstrual cycles of girls should make one reluctant to attribute to the menarche itself the importance as a criterion of maturity which is commonly ascribed to it by writers on adolescence."* The first signs of pubic hair growth and breast development precede menarche by about two years (TANNER, '62).

The time of onset and the duration of puberty vary greatly between children (SCHONFELD, '43). This variation may be due to genetic (PETRI, '35; ITO, '42), climatic (ELLIS, '50), seasonal REYMERT and JOST, '47), nutritional (BRUCH, '41; GARN and HASKELL, '60) or socio-economic and secular (MICHELSON, '44; WILSON and SUTHERLAND, '53) factors.

TANNER's ('62) rating of secondary sex characters if unaccompanied by other evidence is not a clear cut nor a practical guide to the clinician in the determination of the degree of skeletal maturation.

## SKELETAL AGE

Skeletal age is by far the most commonly used indicator of physiological maturity during the growing period. COHN ('24) cites POLAND (in his paper) as the pioneer of hand and wrist roentgenographic techniques. However, it has been stated that RANKE (1896) was one of the first workers to employ roentgenograms to detect the onset of ossification events in the carpals. He studied physical development in relation to the appearance of ossification sites from birth through to adolescence.

Shortly after the advent of roentgenographic technique in 1895, PRYOR commenced collecting material for the study of hand and wrist ossification, publishing a report of his studies in 1905.

In collaboration with PRYOR, ROTCH ('08) used hand and wrist roentgenograms for skeletal assessments. They found that chronological age was a poor indication of a child's general developmental status. They carried out an exhaustive study of the ossification patterns in the extremities stating in 1908, *"From the analyses of 1,000 cases..... I have come to the conclusion that in the process of development from birth to adolescence the normal changes which take place in the wrist compare so closely to other joints that in the great majority of individuals, the wrist may be accepted as a fairly accurate index of* *general development"*. ROTCH ('08) was concerned mainly with the first appearance of calcification in bony centres of the carpals, radius and ulna. A total of thirteen stages of maturity covering the period from birth to the fourteenth year of life were studied. Approximate ages were assigned for the various stages of the rating scale used.

It appears that earlier investigators gave little attention to the morphological changes in individual carpal centres between the earliest calcification and maturity. BARDEEN ('21), however, indicated developmental stages by one of four codes, allocating four codes to each developing carpal centre. These stages were combined into overall ratings of carpal development. He defined eleven such stages, excluding the radius and ulna.

PRYOR ('25, '28) noted that females matured earlier than males, the difference becoming apparent as early as the embryonic stage of development.

BALDWIN ('21) endeavoured to overcome the problems introduced by variation in the order of carpal bone appearance and the differing ossifying stages by using a planimeter to measure the total ossified area directly from the roentgenogram. He reported high correlations between the degree of ossification, height and body weight. However, there was no attempt to correct for variations in the size of the hands of children of equal maturity.

PRESCOTT ('23) and CARTER ('24) suggested a refinement of BALDWIN's method. They each recorded a measurement of a defined area and the total ossified area in the wrist region. The ratio of these two measurements were taken as an index of anatomic maturity. The measurement method was considered to be more reliable than inspection.

TODD ('30a, '30b) developed an inspectional system for rating skeletal development in which an assessment was made on the radial and ulna epiphyses, metacarpal and phalangeal epiphyses, and carpal bones. TODD cited SAWTELL as the first to include the radial and ulna epiphyses. This method differed from previous ones in that TODD studied centres of ossification in the shoulder, knee and foot as well as centres in the hand.

TODD ('37) published an Atlas of standards, which were derived for the left hand and wrist of healthy Cleveland children. GREULICH and PYLE ('50, '59) revised these standards and assigned an exact skeletal age to every bone in the hand and wrist. SPEIJER ('50) and SUTOW and OHWADA ('53) also published standards for Dutch and Japanese children respectively.

In assessing skeletal age it is customary to examine roentgenograms of the left hand and wrist on the assumption that pronounced lateral differences are rare. In the early studies of PRYOR ('05), ROTCH ('08) and BALDWIN ('21), right hand and wrist roentgenograms were used. This practice received much criticism prompting PRYOR ('36) to state that *"regardless of the variations (normal), the ossification is bilaterally symmetrical."* This conclusion was reached after the study of hand and wrist roentgenograms of 554 children from 3 months to 14 years of age.

However, LONG and CALDWELL ('11) studied 200 roentgenograms from subjects ranging in age from early childhood to young adulthood. The mental status of the subjects extended from that of idiots and cretins to the exceptionally bright high school boy. In more than one third of the subjects, developmental discrepancies were found between the right and left wrists. Furthermore, ALLEN ('26) reported marked lateral difference in ossification of the skeleton.

TORGERSEN ('51) found that when lateral asymmetry existed, the left hand and wrist skeleton was usually more advanced than the right. He suggested that asymmetry could be due to a difference in innervation. MENEES and HOLLY ('32), FLECKER ('32) and DREIZEN, SNODGRASSE, WEBB-PEPLOE, PARKER and SPIES ('57) reported that in a majority of individuals the right side was more advanced skeletally than the left. MENEES and HOLLY ('32) reported data which indicated that the side in which ossification was more advanced became the side of dominant function. Lateral asymmetry appears to be more common in the carpal bones than in the long bones of the hand and wrist (BAER and DURKATZ, '57; DREIZEN et al. '57).

SAWTELL ('29), MENEES and HOLLY ('32), FLECKER ('32), TORGERSEN ('51) DREIZEN et al. ('57) and ROCHE ('63) all reported that for practical purposes, discrepancies in ossification sequence and timing between left and right sides were mostly non-significant and, therefore, did not constitute a source of error in the determination of skeletal status.

ACHESON ('54, '57) introduced a new system termed the Oxford method for determining skeletal age as an alternative to the use of TODD's standards which were derived from observations made on American children. Furthermore, the Oxford method provided ratings of skeletal maturation according to a defined scale of measurement. The Oxford method was based on a longitudinal study of the physical development of 650 healthy preschool children in Oxford, England. Oxford Maturity Units were allocated to a bone as each distinct shape change made itself manifest so that the sum total of units scored by a bone at any stage in its development would be an exact measure of its maturity.

TANNER and WHITEHOUSE ('59) and TANNER, WHITEHOUSE and HEALY ('62) introduced a weighted scoring method (referred to hereafter as the T-W technique) for rating skeletal age. The numerical score assigned to each bone was standardized from hand and wrist roentgenograms of 2,564 healthy British children of average socio-economic status. The assessment procedure requires a close inspection of each of 20 bones in order to ensure that they meet the criteria of a defined stage. The individual scores are summed and the total score is read off against a sex-specific scale to provide a skeletal age rating.

Several evaluations of the various methods of skeletal rating have been made. MAINLAND ('53, '54) compared the methods of TODD, and PYLE and her associates, finding that in the hands of an inexperienced observer, TODD's method was more accurate than PYLE's. WEINER and THAMBIPILLAI ('52) also obtained more consistent results using TODD's technique.

ACHESON, FOWLER, FRY, JANES, KOSKI, URBANO and VAN DER WERFF TEN BOSCH ('63) studied the reliability of assessing skeletal maturity from hand and wrist roentgenograms using the Atlas of GREULICH and PYLE ('59). The experiment involved six experienced and two less experienced observers rating skeletal age on 50 hand and wrist roentgenograms of children aged between 2 and 18 years. They found that a single assessment of skeletal age was satisfactory, although some variation in skeletal rating occurred between experienced observers. The results of this study suggest that the carpus should be ignored in difficult assessments as it is subject to pronounced maturational variability.

PRYOR ('07) questioned whether the variability in carpal ossification had a genetic basis. However, he stated that illness or inadequate diet had frequently been proposed to explain for the delay in carpal ossification. This has been substantiated by more recent investigators who include ACHESON ('60), and ACHESON, FOWLER and JANES ('62).

GARN, ROHMANN AND BLEMENTHAL ('66) stated that the ossification sequence polymorphism and sexual dimorphism are prevalent in the post-natal skeleton. They favour a genetical explanation for common sequence polymorphisms. From studies in Guatemala, GARN ('65, '66) found that while ossification timing could be delayed by malnutrition, ossification sequence was little affected.

DREIZEN, SNODGRASSE, PARKER, CURRIE and SPIES ('54) found that chronic malnutrition retarded all of the 28 centres which they observed in the hand, but not all to the same extent. The most generally retarded centres were the middle and distal phalangeal epiphyses. The capitate and hamate were the least retarded.

HEWITT, WESTROPP and ACHESON ('55) and DREIZEN, SNODGRASSE, WEBB-PEPLOE and SPIES ('58) stated that the carpus was most susceptible to interference in maturation because of environmental vicissitude.

Retardation of skeletal maturation in Chinese and West African children (CHAN, CHANG and HSIU, '61; MASSE and HUNT, '63) was found to be intimately related to the nutritional status and environmental conditions. However, the sequence of ossification appeared normal.

BALDWIN, BUSBY and GARSIDE ('28), WALLIS ('31), BAYER and NEWELL ('40), GARN and ROHMANN ('59, '60) and JOHNSTON and JAHINA ('65) were all concerned about the bias in skeletal age assessment introduced by the carpal bones. However, TANNER et al. ('62) justified the heavy weighting of carpals.

FRY ('68) compared the Atlas and T-W techniques. He concluded that *"one cannot say if one technique is correct or the other incorrect, although in theory the T-W technique by its painstaking consideration of twenty bones in the hand and wrist should offer far greater precision than the holistic approach of the Greulich and Pyle Atlas technique".* The comparison showed that skeletal age judged by the G-P Atlas was, on the average, advanced by about one year compared with age assessment by the T-W method.

ROCHE and JOHNSON ('69) compared seven different methods of rating area skeletal ages from individual bone skeletal ages. One method which involved a system of selection and weighting based on the method of TANNER et al. ('62) showed a significant difference to the other methods until ossification had occurred in every carpal bone. Their findings suggested that any method excluding the carpal bones will not alter appreciably the mean area skeletal ages.

## OSSIFICATION EVENTS

The objective of the present investigation is to relate the timing of ossification events readily observed on the hand and wrist roentgenograms in Australian Aborigines with the timing of maximum growth in certain craniofacial dimensions. ABBIE and ADEY ('53b) have published the times of hand and wrist ossifications in an Australian Aboriginal tribe. From their cross-sectional study they found that the times of ossification fell within the European range. The results indicated that in common with other populations, females showed earlier ossification than males. They noted that in Aborigines, ossification of the hook of the hamate, tubercle of the scaphoid, pisiform, ridge of trapezium and sesamoids occur during the circumpuberal period. In the male the pisiform centre appeared at about the same time as the sesamoids opposite the head of the first metacarpal, while in the female it ossified 3 - 4 years before the sesamoids.

The adductor and flexor sesamoid bones of the thumb have received a great deal of attention, although early studies reporting the ossification timing were based on small samples. BALDWIN ('28), TODD ('37), BUEHL and PYLE ('42), JOSEPH ('51), GARN and ROHMANN ('62) and BJÖRK and HELM ('67) reported the times of appearance of the adductor and flexor sesamoids. These studies are summarized in Table 1 below.

TABLE 1

Average time of appearance of adductor and flexor sesamoid bones of the thumb in Caucasoids reported by various authors

| Investigator | Age in Years Girls | Boys |
|---|---|---|
| Baldwin ('28) | 10-14 | 12-16 |
| Todd ('37) | 11.7 | 12.7 |
| Buehl and Pyle ('42) | 10.1 | 12.7 |
| Joseph ('51) | 10-12 | 12-15 |
| Garn and Rohmann ('62) | 10.5 | 12.6 |
| Björk and Helm ('67) | 11.5 | 13.2 |

FLORY ('36) stated that puberal onset could be predicted fairly well by the onset of calcification in the ulna and flexor sesamoids. The sesamoids ossify in girls about two years before the first menstruation. BJÖRK and HELM ('67) found that on the average the sesamoids appeared two and a half years before the first menstruation.

BJÖRK and HELM ('67) in a study of the timing and prediction of maximum puberal growth in body height, found a close association between the age when maximum velocity in growth of body height occurred and the age when the ulna metacarpophalangeal sesamoid of the thumb ossified. They found that the sesamoid did not ossify after maximum puberal skeletal growth, but usually it ossified one year before. As a consequence, they concluded that presence of ossification in the sesamoid would indicate that maximum puberal skeletal growth was imminent or had been reached.

It would seem then that ossification of the sesamoid is a fairly clear indication that the puberal growth period is commencing, particularly as JOSEPH ('51) showed that the pollex sesamoids were found in 100% of adults.

## CRANIOFACIAL GROWTH STUDIES

The first cross-sectional cephalometric analysis of facial growth in Australian Aborigines was reported by CRAVEN ('58). He analysed the lateral cephalometric roentgenograms of 56 Central Australian Aboriginal children and young adults from the Hermannsburg and Haast Bluff Settlements. These films were previously obtained by HEATH ('47). The subjects were of mixed tribal origin. Mean values, sex differences and age changes were determined for many craniofacial variables and the results were compared with a group of Swedes, Bantus, and North American Whites. Alveolar prognathism was most marked in the Australian Aboriginal, and in contrast to the other ethnic groups, it increased with age.

BARRETT, BROWN and MACDONALD ('63a) obtained linear and angular measurements from tracings of lateral head roentgenograms of 58 young adult Australian Aborigines - 31 males and 27 females, in order to measure the degree of prognathism. Prognathism was described in two ways: by the conventional craniometric gnathic index and by angular measurements. Comparisons were made with the findings of previous studies of Aborigines (CRAVEN, '58) and other ethnic groups (BJÖRK, '47; BJÖRK and PALLING, '54; KAYUKAWA, '57). The most striking characteristic was the marked degree of alveolar prognathism of both jaws in the Australian Aboriginal.

BROWN and BARRETT ('64) reported further on the facial morphology and the sex difference in certain facial dimensions of the same young adult group of Australian Aborigines. Average values of facial linear measurements, particularly in the lower face, were greater in males than females. However, there were no significant sex differences in facial shape, as expressed by mean angular variables.

In a more detailed report, BROWN ('65) employed correlation and regression analyses and related prognathism to cranial base morphology and to the size and shape of other dentofacial structures. Early studies in the series of reports on the dental and craniofacial characters of the Wailbri (BARRETT, BROWN and FANNING, '65) were concerned mainly with adults. However, GRESHAM, BROWN and BARRETT ('65) compared the skeletal and denture patterns of Australian Aboriginal children with those from Melbourne, New Zealand and North America. Forty-four Aboriginal children were selected for the study to match the other populations in age and sex distribution; their age ranged from 7 - 9 years. The most marked difference between the groups of children was the proclination and forward position of the incisor teeth in the Australian Aboriginal.

Computer techniques adopted by the Adelaide University Growth Study (BARRETT, BROWN and SIMMONS, '66) made it possible to apply multivariate techniques to the analysis of cephalometric data (BROWN, BARRETT and DARROCH, '65a) and to use factor analysis for comparisons between two ethnic groups (BROWN, BARRETT and DARROCH,'65b).

BROWN ('67) used factor analysis to disclose sources of co-ordination within the craniofacial components. He obtained standardized lateral and postero-anterior roentgenograms of 100 Australian Aboriginal Male skulls housed in the South Australian Museum, Adelaide. Measurements were taken directly from the skulls or directly from the cephalometric roentgenograms.

BARRETT, BROWN and McNULTY ('68) described computer techniques for co-ordinate analysis of linear and angular measurements of cephalometric roentgenograms. McNULTY, BROWN and BARRETT ('68) employed this co-ordinate system of cephalometric analysis based on the mesh diagram method of MOORREES and LEBRET ('62) to study the craniofacial morphology of 65 young adult Central Australian Aborigines.

McNULTY ('68) in a more detailed study examined the overall growth changes in facial morphology, and showed that specific differences existed in the pattern of growth between males and females.

A number of reports on cephalometric analyses of other ethnic groups appear in the literature. An attempt is made to highlight investigations relevant to the present study.

BROADBENT ('37), BRODIE ('41, '53), BJÖRK ('47, '53, '54, '55) and LANDE ('52) analysed craniofacial growth from serial lateral roentgenograms of the head. They all used reference lines for the orientation of records which were registered on various craniometric points. However, these methods have their limitations as all landmarks in the head are subject to growth changes in shape and position. ABBIE ('63a, '63b) has suggested that the anthropometric point hormion, located near the base of the pituitary fossa, has considerable claims for attention as an important fixed morphological point on the grounds that it approximates the location of the notochord tip.

BROADBENT ('37) published results of his investigation on the growth of the human face. This cross-sectional study included 50 girls aged between 3 years and 18 years, and 50 boys between the ages of 3 years and 12 years. All subjects were enrolled in the Bolton Study. Results indicated that the face grows in a downward and forward direction away from the cranial base.

BRODIE ('41) reported the results of a longitudinal study of head growth from serial cephalometric roentgenograms. The material, consisting largely of BROADBENT's collection of cephalometric roentgenograms, comprised 14 sets of serial head plates taken on 21 males between the ages of 3 months and 8 years. The brain case, as well as nasal, upper alveolar and mandibular areas were studied separately. He indicated that the shape and form of the skull is determined at about the third month of life. Growth of the various areas appeared to be so integrated that the various reference points were displaced along a series of straight lines.

LANDE ('52) found from his cephalometric roentgenographic analysis of 34 boys from the Bolton Study, aged between 3 and 18 years, that the rates of growth in the mandible and maxilla differed. The convexity of the face almost always decreased with age after seven years, due to an increase in mandibular prognathism.

BRODIE ('53) studied growth of the head in a group of 19 boys aged between 8 and 17 years from whom serial cephalometric roentgenograms were available. It was evident that the individual pattern of growth was consistent. The nasal floor showed a strong tendency to remain stable throughout the growth period and the junction of the pterygoid process and the maxillary tuberosity was the most stable region in the face.

BJÖRK ('47) investigated facial prognathism in 322 twelve year old boys and 281 males aged twenty-one years. Increase in mandibular prognathism was slightly more accentuated than the increase in maxillary prognathism. As a consequence, a straightening of the facial profile occurred with an increase in age. This was attributed to the greater rate of increase of the ramus height.

In a follow up study (BJÖRK, '53, '55; BJÖRK and PALLING, '54) of 243 twelve-year old Swedish boys, who were re-examined at the age of

20 years, correlations were determined between measurements of cranial base flexion and prognathism. DAVENPORT and RENFROE ('40) used serial roentgenograms to study the development of sella turcica in 46 boys and 50 girls ranging in age from 10 to 18 years. They found that the sex difference in mean area of the sagittal section of sella turcica was established early, as the same annual increase in both sexes occurred between 12 years and 18 years.

FRANCIS ('48) studied growth changes in the pituitary fossa in a group of 418 foetal skulls, 400 living white subjects, 391 living Negro children and 1,131 adult skulls. Age range extended from the fifth foetal month to old age. The pituitary fossa was found to grow rapidly during both the foetal period and the first year of postnatal life. A brief pre-adolescent spurt interrupted a less rapid but uniform childhood growth. Adult dimensions were attained at about the eighteenth year.

BJÖRK ('55, '63, '64, '68) studied facial growth by means of metallic implants inserted into well defined areas of both the mandible and maxilla. He noted the cranium was almost fully developed in size before puberty; in contrast, growth of the face continued to a considerable extent during adolescence. Metallic implants and serial cephalometric roentgenograms made it possible to illustrate the variations in the pattern of growth in the mandible and maxilla.

MEREDITH ('58) reported a longitudinal study of nose height in 80 children, 38 boys and 42 girls, aged between 5 and 12 years. He found that generally an adolescent spurt occurred, but stressed that a considerable degree of individual variability existed. SUBTELNY ('59) confirmed these results in his serial cephalometric roentgenographic analysis of 15 males and 15 females aged 3 months to 18 years.

MAJ and LUZI ('64) studied mandibular growth of 12 boys and 16 girls from serial lateral roentgenograms of the head taken annually from age 9 to 13 years. They showed that females exhibited a greater increase in size of the mandible than boys. This difference was due to the fact that, in females the relative increase in the height of the rami is about one third greater than males. There was no significant relationship between the growth increments of the mandibular body and rami. An attempt was made to predict mandibular growth on the basis of the gonial angle value.

TRACY, SAVARA and BRANT ('65) utilized co-ordinate analysis in a longitudinal study on the interrelations of five dimensions of the mandible in 27 girls. The dimensions were related to height, width and depth of the mandible. Analyses demonstrated that the mandible was not interrelated in height, width and depth.

In a mixed longitudinal cephalometric study SINGH and SAVARA ('66) analysed the maxillary growth of a group of 50 girls aged between 3 years and 16 years. They stressed the importance of utilizing dimensions that strictly define the maxillae and selected seven dimensions for analysis. Growth changes in the maxillae were most marked in measures of height, less in length and least in width.

MAJ and LUCCHESE ('69) reported a serial cephalometric roentgenographic analysis of facial growth in 13 boys and 14 girls from age 9 years to 17 years. They studied seven linear and two angular dimensions in the face, and an analysis of the relations between these variables revealed that the inclination of the mandible was a prime factor in affecting the antero-posterior position of the jaws.

THE RELATION BETWEEN SKELETAL MATURATION AND FACIAL GROWTH

The relation between skeletal maturation and facial growth in Australian Aborigines has not previously been reported.

In order to study the rates of growth in the face NANDA ('55) measured seven linear dimensions directly on serial lateral roentgenograms of the head in ten male and five female subjects from 4 - 20 years of age. The growth curves of all facial dimensions were typical of general skeletal growth curves. However, the time of circumpuberal maximum growth was slightly later in facial dimensions than in body height. In this small sample, girls showed relatively less facial growth than boys during adolescence.

ROSE ('60) used cross-sectional material to study the relation of area measurements of the face to several body dimensions. The analysis was restricted to individuals aged 9 to 18 years. The facial areas were measured directly with a planimeter. The results showed that stature and body weight were more effective guides to facial development in the circumpuberal period than chronological or skeletal age.

BAMBHA ('61) made a quantitative analysis of five skull measurements on serial lateral cephalometric roentgenograms of 25 boys and 25 girls enrolled in the growth study at the Child Research Council in Denver. The study revealed that the face followed the characteristic skeletal growth pattern, including distinct adolescent changes. The time of the maximum growth spurt in the face usually occurred a little after the spurt in body height. The face continued to show a small increment of growth after the growth in body height had been completed. Compared with boys, girls had smaller absolute measurements, a slower rate of growth and tended to mature about 2 - 3 years earlier.

BAMBHA and VAN NATTA ('63) in a longitudinal study of skeletal maturation and facial growth during adolescence employed only one dimension, sella-gnathion (s-gn), as a measure of the time of maximum growth in the face. They found an association between skeletal maturation and facial growth during the adolescent period at the two extremes of skeletal development. Individuals who showed advanced skeletal maturation revealed an early adolescent facial spurt, while those with retarded skeletal maturation tended to mature later. There was a wide variation between these two groups.

In three separate studies JOHNSTON, HUFHAM, MORESCHI and TERRY ('65) compared skeletal maturation, cephalofacial development and chronologic age. They found that certain cephalofacial parameters were closely related to the processes of skeletal maturation. It was clearly demonstrated that spurts and lags in maturation activity in the mandible were accompanied by similar spurts and lags in some aspect of growth. A delay in skeletal maturation was often found to be associated with a particular kind of malocclusion.

A serial investigation of facial and statural growth in 25, seven to twelve year old children by PIKE ('68) showed that in all individuals a close approximation to a constant rate of growth occurred in stature and in the facial dimensions studied.

HUNTER's ('66) longitudinal study on 25 males and 34 females from seven years up to adolescence comprises the most comprehensive group from the files of the Child Research Council in Denver. Seven linear measurements were used to evaluate the growth of the face. The time of peak velocity in height was determined for each subject from the incremental growth curve derived from his anthropometric measurements. Skeletal age was used to categorize subjects into retarded, average, and accelerated groups. Results showed that maximum facial growth was coincident with maximum growth in height in the majority of subjects. This differed slightly to the results of NANDA ('55) and BAMBHA ('61).

SINGH, SAVARA and MILLER ('67) examined the size relationships of selected face and body dimensions at two year intervals in a mixed longitudinal study of 33 girls from 6 to 14 years of age. The facial and the body dimensions revealed no consistent relationship. Stature, calf bone width, weight and body surface area appeared to be the best indicators of facial development.

# MATERIALS AND METHODS

## I. MATERIAL

The relations between ossification of selected bones of the carpus, and the timing of maximum growth in stature and facial dimensions were studied in 88 Central Australian Aborigines - 52 males and 36 females, aged between 8 and 18 years. Observations of ossification events and measurements of facial dimensions were obtained from standardized roentgenograms of the hand and wrist area and head.

The subjects studied belong mainly to the Wailbri tribe of Australian Aborigines living under settlement conditions at Yuendumu, 185 miles north-west of Alice Springs (Fig.2). A few Pintubi children were included in the group. All subjects were of pure aboriginal ancestry so far as can be ascertained. The settlement was established by the Commonwealth Government in 1946 to provide food, clothing, medical care and schooling for Aborigines living in the region.

Within the settlement compound at Yuendumu there are houses for administrative staff, a small hospital, school buildings, a large dining hall and kitchen, stores and workshops. The hospital and infant welfare clinic are staffed by trained nurses who attend to the immediate medical needs of the community and supervise the care of pregnant women, babies and small children.

Most families live in homes provided by the Governement. However,

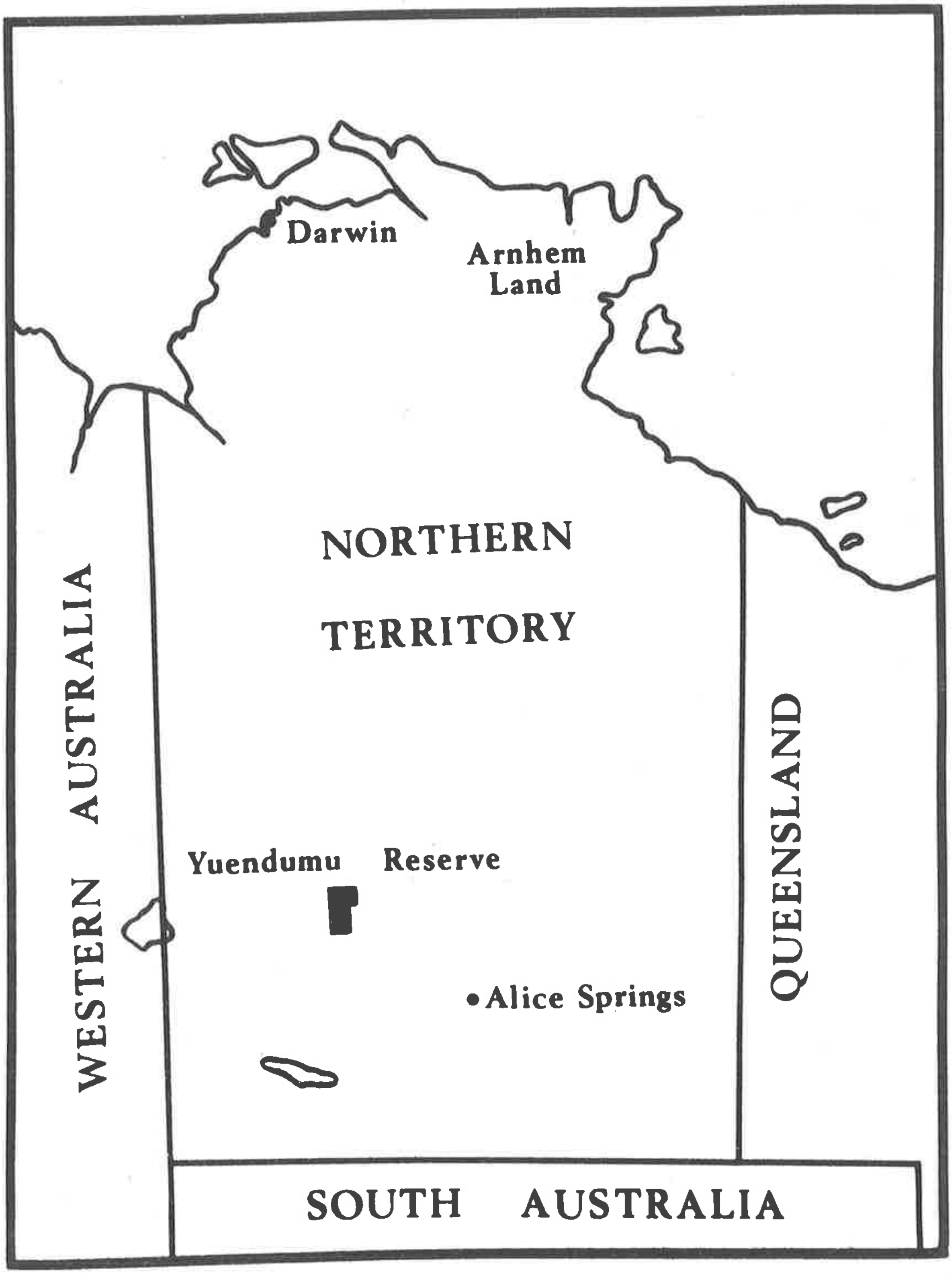


Fig. 2. Location of Yuendumu Settlement.
(Courtesy Dr. T. Brown, Dept. of Dental Science, University of Adelaide, Adelaide, South Australia)

those who prefer primitive living conditions build crude shelters away from the Settlement compound. Although the majority of adults are employed by the Government on the Settlement, some are engaged on nearby cattle stations or on a mining enterprise in the vicinity. Further income is derived from maternity allowances, child endowment, and age and invalid pensions.

The Settlement staff provides low cost meals daily at the community dining hall. However, those Aborigines able to pay for food supplies at the Settlement store often prefer to cook for themselves.

Prior to 1946, most Wailbri were following a simple hunting and food gathering way of life. However, under settlement conditions, European influence has imposed different environmental conditions which provide a unique opportunity of studying a geographically isolated tribe of Aborigines.

TINDALE ('53) reported that in 166 marriages of members of the Wailbri tribe only 8% were with members of other tribes. He regarded this tribe as a fairly homogeneous group. It is highly likely that the community is inbred.

## PREVIOUS STUDIES OF THE WAILBRI

Various aspects of the general anthropology of the Wailbri have been published by CAPELL ('52), ABBIE and ADEY ('53a,'53b, '55). SIMMONS, GRAYDON and SEMPLE ('54), CLELAND and TINDALE ('54), POIDEVIN ('57), SCHULTZ ('58), ABBIE ('57, '61a, '61b, '63c, '66, '67), and MEGGITT ('62).

Professor T.D. Campbell first visited the Yuendumu Settlement in 1951. He regarded the Settlement as especially suited to dental studies (BARRETT, '65) and as a result annual expeditions have been made by members of the Department of Dental Science, The University of Adelaide. Earlier studies reported were mainly concerned with the effects of changing environment (CAMPBELL and BARRETT, '53; CAMPBELL, SIMPSON, CORNELL and BARRETT, '54; CRAN, '55; BARRETT, '64, '69), and oral physiology (BARRETT,'56a).

Oral conditions in the Wailbri have also been investigated. Particular attention has been directed to dental fluorosis (BARRETT, '56b), gingival conditions (BARRETT, '53a; CRAN, '55, '57), diet and dental caries (BARRETT, '53a; CRAN, '59, '60a), histology of the teeth (CRAN, '60b), oral microbiology (CRAN, '64) and oral pigmentation and oral disease (READE, '62, '64).

Tooth morphology and dental occlusion in the Wailbri have been studied extensively by BARRETT and his colleagues. The emphasis has been on the metric characters of the permanent and deciduous dentitions (BARRETT, BROWN and LUKE, '63; BARRETT, BROWN and MACDONALD, '63b; BARRETT, BROWN,ARATO AND OZOLS, '64), the size and shape of the dental arches (BARRETT, BROWN and MACDONALD, '65; BARRETT and BROWN, '68; CHENG, '70), the patterns of tooth attrition (BARRETT, '53a, '60, '69), functional tooth occlusion (BARRETT, '53b, '57a, '58) and the sequence of tooth eruption (BARRETT, '57b; BARRETT, BROWN and CELLIER, '64; BARRETT and BROWN, '66).

Two further aspects recently investigated are variations in crown morphology of primary teeth (KUUSK, '70), and patterns of growth in height (BROWN and BARRETT, '70).

in 1961, the methodology of the study was extended to include a selection of anthropometric body measurements, standardized hand and wrist and cephalometric roentgenograms. Consideration was given to variations in the relation between skeletal maturation, the dental arches and craniofacial structures. As sufficient records had not been accumulated, previous investigations have been cross-sectional and mixed longitudinal, and concerned mainly with craniofacial morphology in adults only. These reports deal with facial and alveolar prognathism (BARRETT, BROWN and MACDONALD, '63a; BROWN and BARRETT, '64; BROWN, '65), the use of factor analysis in craniometric research (BROWN, BARRETT and DARROCH, '65a,'65b), and the application of automatic methods of measurement with the use of co-ordinate system of analysis (BARRETT, BROWN and McNULTY, '68; McNULTY, BROWN and BARRETT, '68; McNULTY, '68).

A preliminary comparison of facial characteristics in Australian Aboriginal children and children from Melbourne, New Zealand and North America has been made by GRESHAM, BROWN and BARRETT ('65).

## SELECTION OF SUBJECTS

The following criteria were strictly adhered to in the selection of subjects.

1. Pure aboriginal ancestry.
2. A recorded and confirmed birth-date.
3. An age range of 8 - 18 years.

4. An absence of physical deformity.
5. A minimum of three serial hand and wrist roentgenograms.
6. A minimum of four serial lateral cephalometric roentgenograms obtained with the teeth in occlusion.

Over 1,615 single casts, 1,070 cephalometric roentgenograms and hand and wrist roentgenograms have been collected since the longitudinal growth study began.

The material used in the present study is listed in Tables 2 and 3, indicating the number of records available and the distribution of hand and wrist and lateral cephalometric roentgenograms according to chronological age of the subject. The appearance of ossification events and facial growth velocity calculations were recorded prior to the field expedition during May, 1970. Hand and wrist roentgenograms obtained in 1970 were included only for those subjects in which ossification events had not appeared or were uncertain. Lateral head roentgenograms obtained in 1970 were included only if they increased the sample size when the criteria for selection of peak growth velocity were applied (Chapter 5).

Although this study is concerned mainly with the relation between skeletal maturation and craniofacial growth, it seems relevant to discuss briefly the dental state of the subjects. Important features are discussed in Appendix A.

TABLE 2(a). Distribution of subjects according to the number of serial hand and wrist roentgenograms.

| Number of Serial Records | Male | Female | Total Subjects | Total Films |
|---|---|---|---|---|
| 3 | 2 | 8 | 10 | 30 |
| 4 | 19 | 7 | 26 | 104 |
| 5 | 16 | 11 | 27 | 135 |
| 6 | 15 | 9 | 24 | 144 |
| 7 | - | 1 | 1 | 7 |
| Total | 52 | 36 | 88 | 420 |

TABLE 2(b). Distribution of subjects with hand and wrist roentgenograms according to age.

| Age | Males | Females | Total |
|---|---|---|---|
| 8 | 17 | 16 | 33 |
| 9 | 22 | 21 | 43 |
| 10 | 31 | 29 | 60 |
| 11 | 40 | 26 | 66 |
| 12 | 41 | 28 | 69 |
| 13 | 44 | 18 | 62 |
| 14 | 30 | 14 | 44 |
| 15 | 13 | 8 | 21 |
| 16 | 10 | 6 | 16 |
| 17 | 4 | 2 | 6 |
| 18 | - | - | - |
| Total | 252 | 168 | 420 |

TABLE 3(a). Distribution of subjects according to the number of serial lateral cephalometric roentgenograms.

| Number of Serial Records | Male | Female | Total Subjects | Total Films |
|---|---|---|---|---|
| 3 | 2 | 4 | 6 | 18 |
| 4 | 9 | 5 | 14 | 56 |
| 5 | 7 | 5 | 12 | 60 |
| 6 | 15 | 11 | 26 | 156 |
| 7 | 15 | 8 | 23 | 161 |
| 8 | 4 | 3 | 7 | 56 |
| Total | 52 | 36 | 88 | 507 |

TABLE 3(b). Distribution of subjects with lateral cephalometric roentgenograms according to age.

| Age | Males | Females | Total |
|---|---|---|---|
| 8 | 25 | 17 | 42 |
| 9 | 27 | 22 | 49 |
| 10 | 37 | 30 | 67 |
| 11 | 40 | 28 | 68 |
| 12 | 40 | 30 | 70 |
| 13 | 43 | 24 | 67 |
| 14 | 36 | 19 | 55 |
| 15 | 27 | 14 | 41 |
| 16 | 18 | 11 | 29 |
| 17 | 10 | 7 | 17 |
| 18 | 1 | 1 | 2 |
| Total | 304 | 203 | 507 |

## II. METHODS

For descriptive purposes, the methods are divided into (1) General methodology, (2) Roentgenographic methods, (3) Stature, (4) Hand and wrist ossification events, (5) Reference points and reference lines, (6) The variables studied, and (7) Statistical methods.

The exact method of measuring stature, assessing skeletal age and the presence of ossification events and the measurement of individual craniofacial components are described in later chapters.

### (1) General Methodology.

Statural observations were obtained from the somotometry record forms which are kept with the roentgenograms, photographs and casts in the Dental Anthropology Laboratory of The University of Adelaide.

#### Recording of observations

A data sheet was designed for recording all observations of the study. This form is identified as Dentgro Project, Skeletal Maturation Study, Form 7, and is illustrated in Appendix B. The data recorded on each sheet represented the observations for a field trip of a particular subject.

The ossification events appearing on hand and wrist roentgenograms were recorded on data card 1, and stature as well as all measurements derived from lateral cephalometric roentgenograms were recorded on data card 2. Column 80 on data card 2 was used to identify the year of the trip in order to facilitate the calculation of the time interval between observations with respect to the selection of maximum velocity.

To reduce errors, observations were recorded directly on the data sheets after the subject's identification number, sex, chronological age and trip record number had been checked. All observations were entered carefully on the data sheets in red ink and subsequently transferred onto standard 80-column punched cards by operators in the Computing Centre of The University of Adelaide. In the Dental Anthropology Laboratory the data deck was appropriately arranged and a computer listing was made to facilitate the detection of any remaining punching errors.

(2) Roentgenographic Methods

The roentgenograms were taken under field conditions at Yuendumu, using conventional equipment modified to suit the requirements of the study. These modifications have previously been described by BROWN ('65). However, the radiographic techniques used followed closely accepted methods previously published (KROGMAN and SASSOUNI, '57; SALZMANN, '61).

A Watson Victor Model Konrad 3T X-ray machine, modified for use in the field was used for both hand and wrist roentgenograms as well as for lateral cephalometric roentgenograms. The power supply available at the Settlement was a reasonably stable 240 volts A.C. This was generated by a 20 KvA alternating current generator powered by a diesel motor.

Cephalostat

M.J. Barrett designed the head-holder (Fig. 3). It was similar in design to that suggested by BJÖRK ('50). The main frame was cast in aluminium. The ear rods were fitted with wooden supports fastened

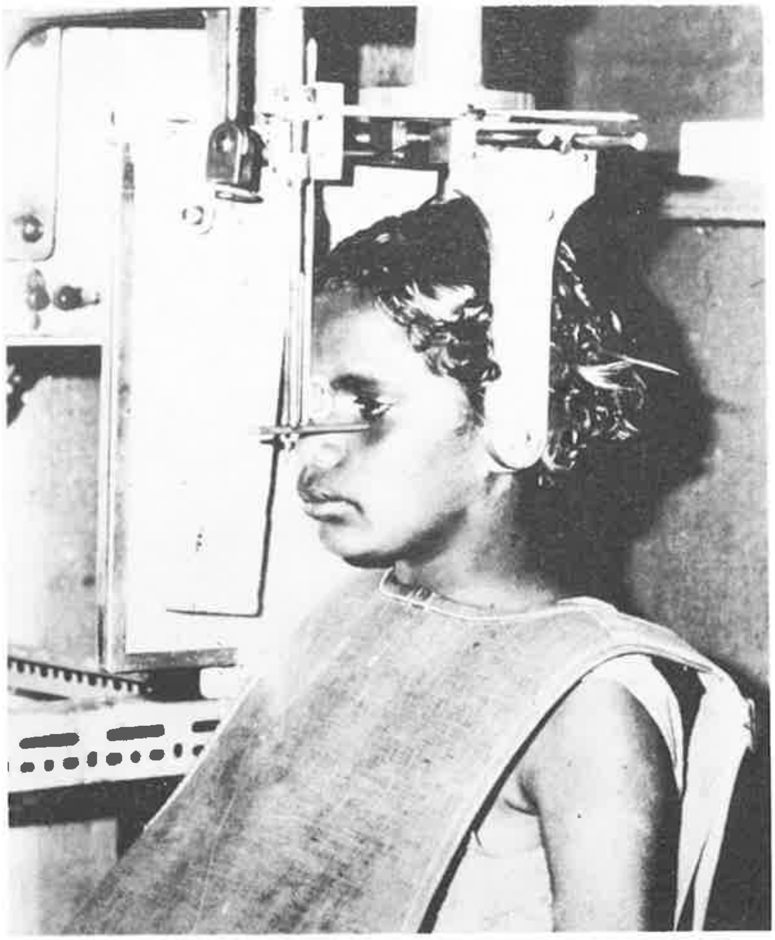

Fig. 3. Head holder used during field studies at Yuendumu

to a lever system which moved both left and right ear rods simultaneously. This method ensured that the median sagittal plane remained constant for all subjects regardless of age or head-breadth.

The head position was made more secure by using a median nasion rest which was adjustable in both vertical and horizontal directions. An orbitale indicator was also fitted to the cephalostat. This was used for checking head orientation after rotation of the subject for postero-anterior films.

The cephalostat and the X-ray head were assembled on steel frames which were prefabricated and securely bolted to the floor following test exposures for correct alignment.

### Soft Tissue Contrast

An aluminium wedge 250 mm x 65 mm x 20 mm tapering to 1 mm was placed between the facial profile and the film at the time of exposure of the lateral films. As a result, the soft tissue profile was clearly evident without any impairment to the definition of the underlying bony structures.

### Positioning of Subjects

For the hand and wrist roentgenograms the subjects stood in line with the screen behind the cassette holder and the right arm extended. The film was held against the screen by the right hand and wrist. The fingers were slightly separated (Fig. 4). If the wrist appeared distorted the subject was asked to stand a little behind the screen. This position corrected the wrist distortion without causing a great deal of confusion to the subject.

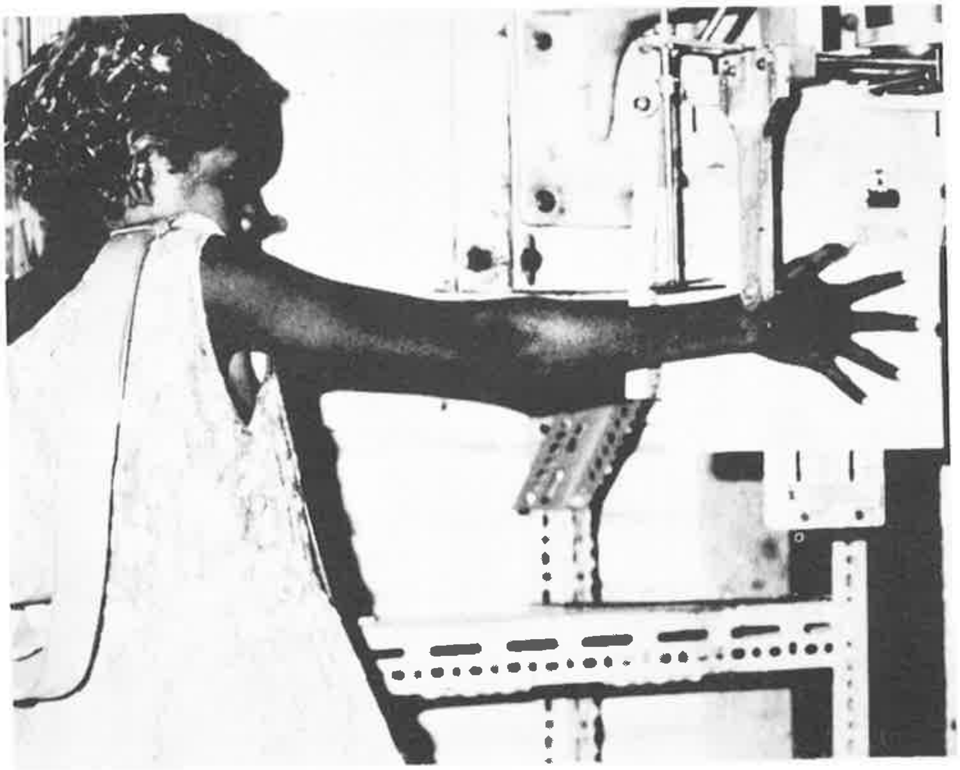

Fig. 4. Subject positioned for hand and wrist roentgenogram

For head roentgenograms, the subject was seated on an adjustable stool, so that the level of the external accoustic meati could be adjusted to the height of the ear rods of the cephalostat. The seated subject was positioned in the cephalostat and the head was fixed by means of the ear rods and nasion support after a natural head position was obtained. This was best accomplished by asking the subject to focus his eyes on a spot on the far wall at eye level.

Although this report is limited to the results obtained from hand and wrist films as well as lateral head films taken in the tooth position, other exposures were made during each expedition for future study.

The tooth position radiographs were obtained by asking the subject to hold thin strips of paper between the back teeth on both sides simultaneously. Wherever possible the tooth position was visually checked before the radiograph was exposed. In practice it was found that it was best to avoid using verbal directions to bite or close as this very often caused confusion for the subject, particularly those with poor command of English. In a significant number of subjects the teeth did not interdigitate maximally on right and left sides together. This occlusal condition, which is due to a disparity in the widths of upper and lower dental arches is being studied further by the Adelaide Dental Anthropology Group. BARRETT ('58) was the first to describe this occlusal condition in the Wailbri. However, it was subsequently found in a different group of Central Australian Aborigines by HEITHERSAY ('61). Furthermore, these occlusal relations have been described by BEYRON ('64) and subsequently noticed in other ethnic groups.

Specification of X-ray Beam

For each hand and wrist roentgenogram the cone of the X-ray machine was centered over the head of the third metacarpal bone at a distance of 100 cm for the expeditions from 1961-1966 and 195 cm from 1967-1970.

The anode to median sagittal plane distance was kept constant for all subjects at 180 cm. BJÖRK ('50) suggested a median sagittal plane-film distance of 10 cms. However, this distance proved to be impracticable with many subjects because the cervical portion of the vertebral column of the Australian Aborigine is considerably shorter than that of the European (WOOD-JONES, '38). As a consequence, shoulder interference with the lower margin of the cassette holder forced the subject into an unnatural sitting posture. Therefore, the median sagittal plane to film distance was set for all subjects at 15 cm to ensure they could be seated comfortably.

The above distances produced a calculated enlargement of 8.3% for linear structures situated in the median sagittal plane.

Film Type

From 1961 to 1969, all hand and wrist, and head exposures were made on Kodak Blue Brand Safety Film, 20 cm x 25 cm (8" x 10") and 25 cm x 30 cm (10" x 12") respectively. Alignment tests were made on standard periapical dental films. In 1970, film processing was changed from manual to automatic and Kodak RP/S X-omat Medical X-ray film with a tinted estar saftety base was used. Watson Victor Kontak cassettes fitted with two Dupont stainless steel fast speed intensifying screens were used.

Before the subject presented for the roentgenographic survey, six cassettes were loaded. This permitted repeat exposures to be made without unduly disturbing the subject.

Lead numbers, clipped to the corner of each cassette, identified exposed films with the subject's expedition number.

Film Exposure Data

Hand and wrist and lateral head roentgenograms of a satisfactory quality were obtained on all subjects on each expedition from 1961-1966 and 1961-1969 respectively when the following average settings were used.

| | | | |
|---|---|---|---|
| Hand and Wrist Roentgenograms | 50 Kv | 20 MA | 0.5 sec. |
| Lateral Head Roentgenograms | 78 Kv | 15 MA | 0.5 sec. |

However, with the change in hand and wrist roentgenographic methods in 1967 and with the introduction in 1970 of the new type film which is best suited to automatic processing, the following settings were employed.

| | | | |
|---|---|---|---|
| Hand and Wrist Roentgenograms | 70 Kv | 30 MA | 2 sec. |
| Lateral Head Roentgenograms | 80 Kv | 20 MA | 0.6 sec. |

During the period of the field survey test films were developed from time-to-time and if necessary adjustments made to the exposure data. Furthermore, films were air freighted to Adelaide for processing and report (quality control).

On each trip the X-ray unit, the operator, and the work area were monitored for radiation and found to be well within accepted safe levels. Nevertheless, as a precautionary measure all subjects were covered by a lead apron during exposure to radiation.

### Film Processing

The roentgenograms were developed in Kodak liquid X-ray developer Type 2, and fixed in Kodak liquid X-ray fixer according to the recommended time-temperature specifications of the manufacturers. A final wash of about one hour was given in clear running water, after which the films were allowed to dry at room temperature. The hand and wrist roentgenogram and the set of head roentgenograms were placed in a separate manilla folder. However, each folder supplied the same information, namely, the subject's delta number, age and expedition number. All roentgenograms were filed in delta number order and each subject's records were filed in order of trip. These records were always available for immediate perusal in the Dental Anthropology Laboratory.

Automatic film processing was used for the 1970 film exposure. This unit*, which is housed in the Radiology Department of the Adelaide Dental Hospital, greatly simplified film processing as all roentgenograms were uniformly developed in several hours.

The unit was programmed so that all films were in Ilford Phenisol X-ray developer for two minutes, washed for one minute and in Ilford Hypam X-ray rapid fixer for four minutes. They were washed again for four minutes and moved into a drying cabinet for five minutes before each film was released from its hanger and returned through a shute in

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* Refrema Processing Unit, manufactured in Sweden.

the viewing area. The hanger was automatically fed back to the loading position.

Hypam hardener was added to the fixer in order to prevent scratching of the films.

(3) Stature

Height was measured using an anthropometer (Fig. 5) with the subject standing in a relaxed position, eyes directed horizontally.

One observer recorded height measurements on six of nine visits. On the other three occasions different observers made the measurements following the standard technique.

(4) Ossification Events

The ossification events initially considered in a pilot study and illustrated in Fig. 6 included:

* radial capping
* appearance of pisiform
* hooking of hamate
* approximation of trapezium with base of second metacarpal
* appearance of ulna metacarpophalangeal sesamoid of the thumb
* epiphyseal capping of proximal phalanx of the thumb
* fusion of the distal phalanges I - V

According to average times stated in the Greulich-Pyle Atlas ('59) some of these events often occur after the period of maximum puberal growth and were, therefore, excluded from further study. Others were excluded because of difficulties in consistently visualizing the precise stages in question on the radiographs.

Fig. 5. Measurement of standing height using the anthropometer constructed for field studies

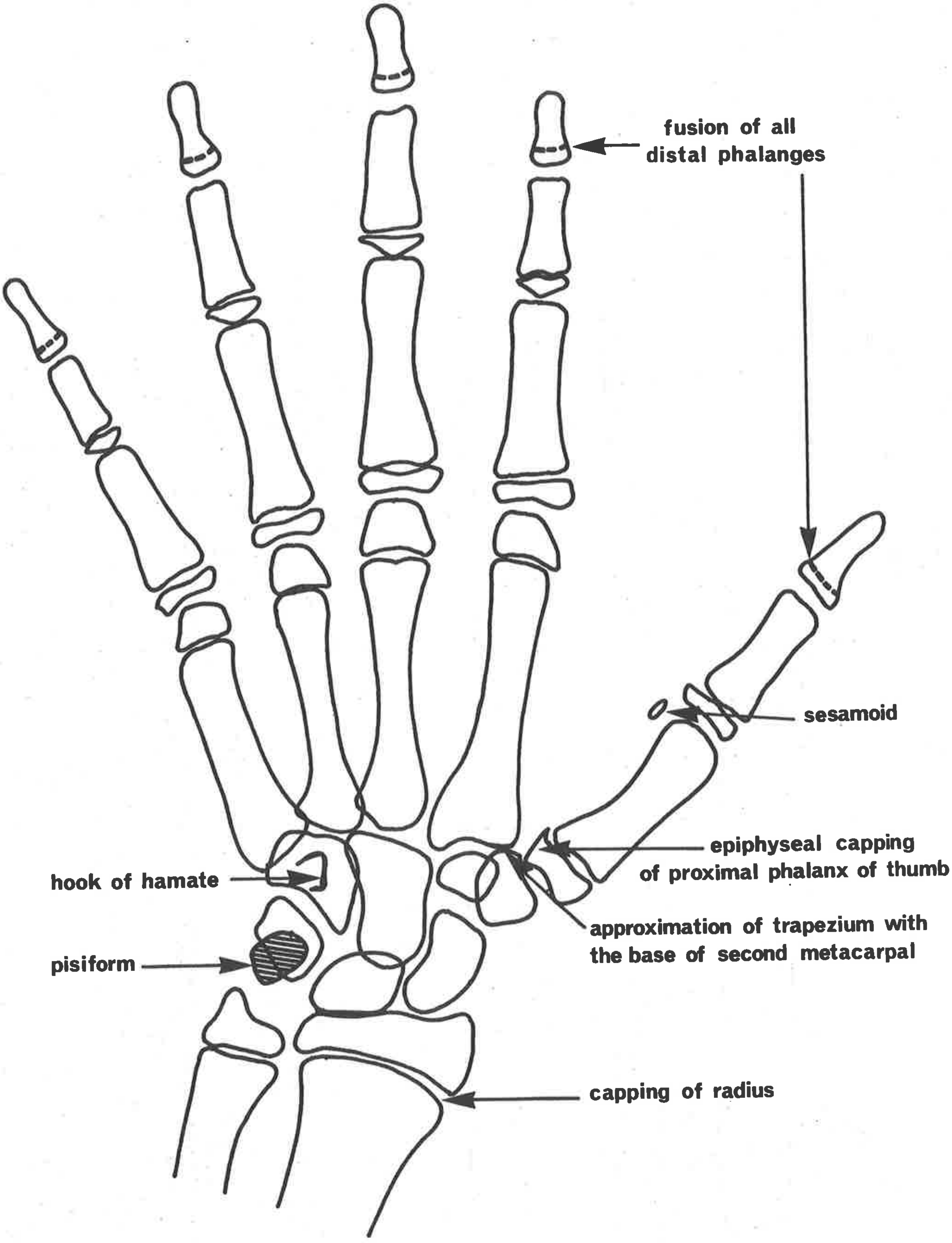


Fig. 6. Ossification events inspected in preliminary analysis.

Finally, the following three ossification events were selected for detailed study:

(1) appearance of pisiform;

(2) hooking of hamate;

(3) appearance of ulna metacarpophalangeal sesamoid of thumb.

(5) Reference Points and Reference Lines (Fig. 7).

The reference points were located on each roentgenogram and all measurements were made directly on the film. All reference points are situated in the median sagittal plane or are projected onto that plane. When double projection occurred mid-points of the two images were used. All reference points and reference lines were located according to the definitions of BJÖRK ('60).

Reference Points

1. Articulare (ar): intersection between the contour of the external cranial base and the dorsal contour of the condylar head.
2. Gnathion (gn): lowest point on the mandibular symphysis.
3. Gonion (go): a point on the bony contour of the gonial angle located by the bisection of the angle formed by the mandibular line and the ramus line.
4. Infradentale (id): highest and most prominent point on the lower alveolar arch.
5. Nasion (n): most anterior point of the fronto-nasal suture.
6. Pogonion (pg): most prominent point on the chin.
7. Prosthion (pr): lowest and most prominent point on the upper alveolar arch.

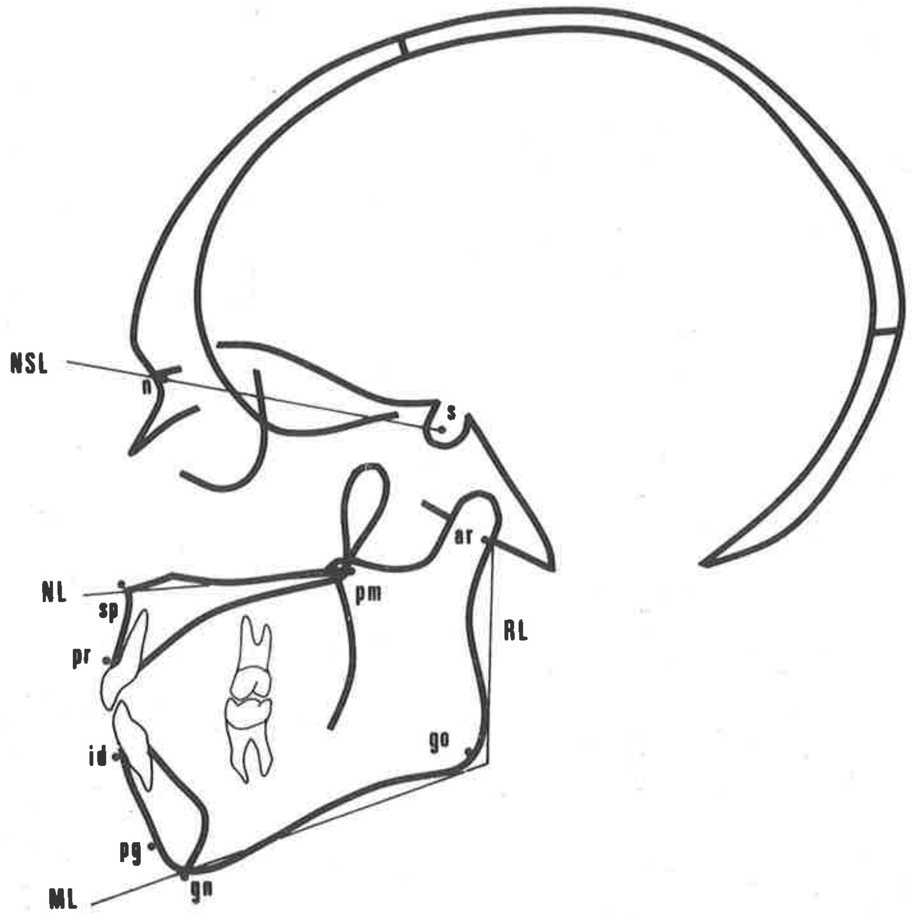


Fig. 7. Roentgenographic reference points and reference lines

8. Pterygomaxillare (pm): point representing the dorsal surface of the maxilla at the level of the nasal floor. The point is located on the dorsal contour of the maxilla, which, above, forms the anterior limit of the pterygopalatine fossa, where this contour intersects that of the hard and soft palates.
9. Sella (s): centre of the bony crypt known as sella turcica. The upper limit of the sella turcica is defined as the line joining the tuberculum sella and the dorsum sellae.
10. Spinal point (sp): (acanthion): apex of the anterior nasal spine.

Reference Lines

1. Nasion-sella line (NSL): line joining the nasion to the sella.
2. Nasal line (NL): the straight line passing through the spinal point and pterygomaxillare.
3. Mandibular line (ML): tangent to the lower border of the body of the mandible through gnathion.
4. Ramus line (RL): tangent to the posterior border of the mandibular ramus and through the articulare.

(6) Variables Studied

Standing height: the distance from the highest point of the top of the head in the mid-sagittal plane to the floor (ASHLEY-MONTAGU, '60).

Ossification Events (Fig. 8)

Appearance of Pisiform: pisiform bone was considered present when it was visible on the hand and wrist roentgenogram.

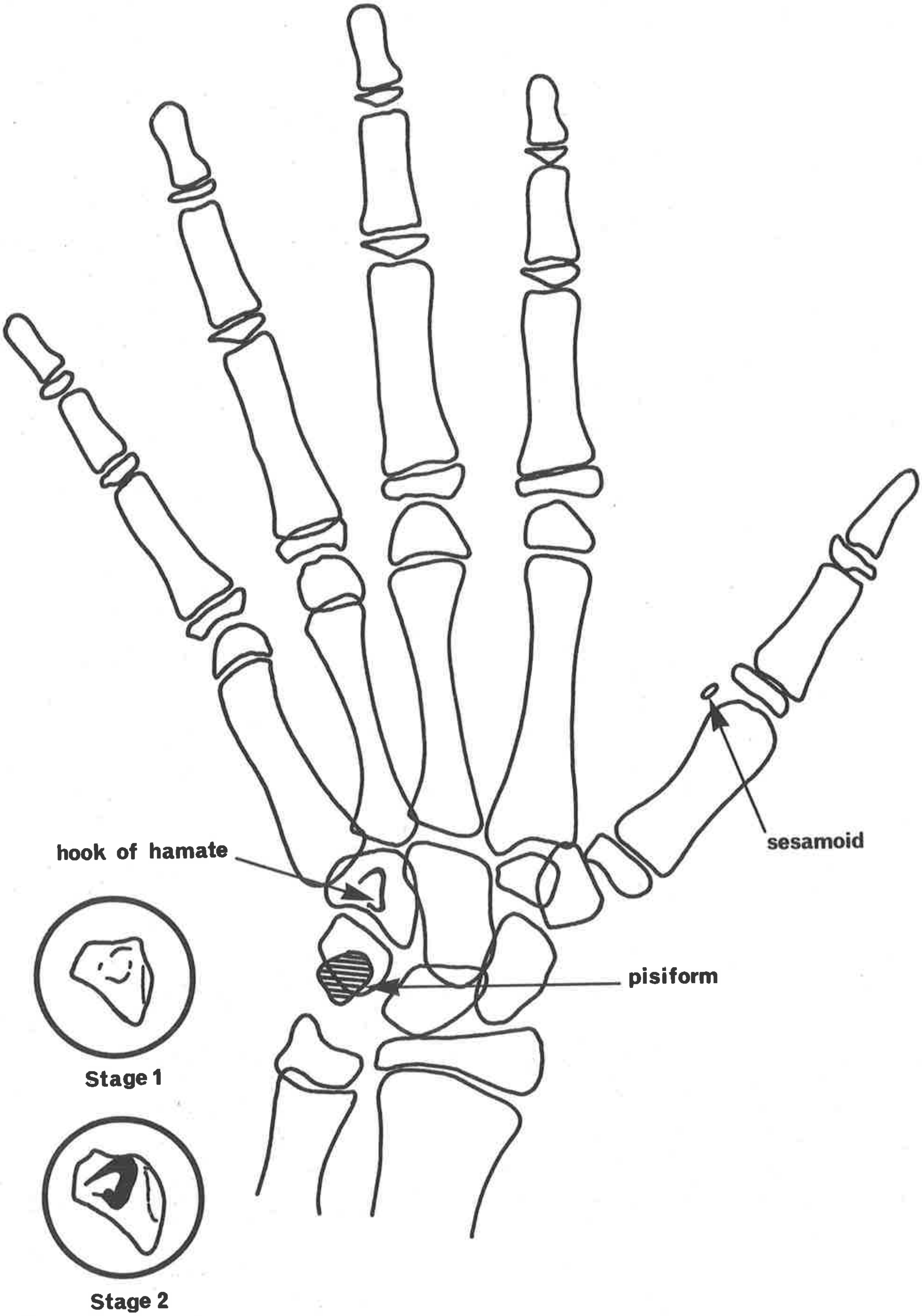


Fig. 8.    Ossification events inspected in final analysis.

Hook of Hamate: hook of hamate was considered present when a radioopaque outline was visible within the upper section of the hamate bone on the hand and wrist roentgenogram. Two distinct stages of this event were recorded.

Stage 1: a fine, incomplete radioopaque outline. This stage corresponds to Tanner, Whitehouse and Healy Stage 7.

Stage 2: a distinct radioopaque outline. This stage corresponds to Tanner, Whitehouse and Healy Stage 8.

Appearance of ulna metacarpophalangeal sesamoid of thumb: sesamoid bone was considered present when it was clearly visible on the hand and wrist roentgenogram.

Size of ulna metacarpophalangeal sesamoid of the thumb: maximum diameter of the ulna metacarpophalangeal sesamoid of the thumb.

Craniofacial Dimensions (Fig. 9)

The variables listed below include measures of the cranial base, upper and lower jaws, and various segments of the naso-maxillary complex.

Cranial Base

Anterior cranial base length (n-s): the distance between nasion and sella.

Maxilla

Maxillary jaw base length (pm-s): the distance between pterygomaxillare and spinal point.

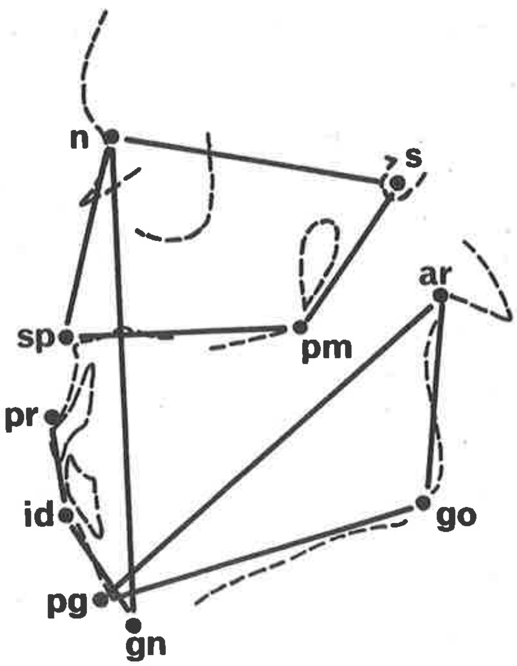


Fig. 9. Craniofacial dimensions measured.

Mandible

Total length (pg-ar): the distance between pogonion and articulare.

Corpus length (pg-go): the distance between gonion and pogonion.

Ramus height (ar-go): the distance between gonion and articulare.

Facial Height

Morphological face height (n-gn): the distance between nasion and gnathion.

Upper face height (n-sp): the distance between nasion and spinal point.

Mandibular face height (id-gn): the distance between infradentale and gnathion.

Middle face height (pr-id): the distance between prosthion and infradentale.

Posterior upper face height (pm-s): the distance between pterygomaxillare and sella.

(7) Statistical Methods.

The statistical parameters - mean, standard deviation, standard error of the mean and range (minimum and maximum) were computed for each variable studied. In addition, associations between pairs of variables were expressed by the coefficient of linear correlation. Formulae of these parameters are listed in Table 4.

TABLE 4. Statistical Parameters.

| Symbol | Parameter | Determination |
|---|---|---|
| $\overline{X}$ | Arithmetic mean | $\frac{\Sigma X}{N}$ |
| S | Standard deviation | $\sqrt{\frac{\Sigma (X - \overline{X})^2}{N - 1}}$ |
| $\varepsilon(\overline{X})$ | Standard error of the mean | $\frac{S}{\sqrt{N}}$ |
| $r_{xy}$ | Correlation coefficient | $\frac{\Sigma (X - \overline{X})(Y - \overline{Y})}{\sqrt{\Sigma (X - \overline{X})^2 \Sigma (Y - \overline{Y})^2}}$ |

X and Y are observed scores and N is the number of observations

To assess the significance of differences between the variances and means of two groups, the F-ratio test of Snedecor and the t-test of Student were used.

For each variable studied the coefficient of variation $\left(\frac{S}{\overline{X}} \times 100\right)$ and the Pearsonian measures of skewness$(\sqrt{b_1})$ and kurtosis$(b_2)$ (PEARSON and HARTLEY, '54), were calculated to provide additional information, particularly on the shape of the distributions. These parameters, however, are not included in the Tables. Judging from the measures of skewness and kurtosis, most variables were distributed normally.

All calculations were carried out on the CDC 6400 computer situated in The University of Adelaide.

CHAPTER III

# ERRORS OF THE METHODS

In biometric research, it is essential to establish the degree of accuracy of the methods empolyed. Limitations in techniques and instruments will give rise to errors of observations. If it can be established that these errors are small in comparison with the variability of the measurements used, then they can be regarded as being within acceptable limits.

The methods used to test the accuracy of the results are discussed under three headings:

(1) Skeletal age and sesamoid diameter;

(2) Ossification events in hand and wrist roentgenograms;

(3) Lateral cephalometric roentgenograms.

In each of the three phases of the study double determinations were made and analysed by Dahlberg's method ('40) in order to determine the magnitude of experimental errors and the extent to which they affected results.

## (1) Skeletal Age and Sesamoid Diameter

CARTER ('26) stated that considerable alterations in the size and shape of the projections of the carpal bones occurred when the hand was flexed during radiography. He also stated that FICK ('01) selected the "straight position" as a standard position with which other positions could be compared. The hand is in the straight position when the long axis of the third metacarpal bone almost corresponds to that of the forearm.

To select a method of evaluating skeletal age and to establish the effect of hand position on this rating and on the diameter of the ulna metacarpophalangeal sesamoid of the thumb, a series of double determinations was made.

The accuracy and consistency of recordings was determined by making two separate assessments of each observation at least 24 hours apart. Data were recorded on IBM coding sheets for transfer to punch cards.

Series 1

A preliminary study was undertaken in order to assess the consistency of two commonly used methods for assessing skeletal age. Hand and wrist roentgenograms of 25 Aborigines and 25 Caucasoids were selected at random and skeletal age assessments were made on each film with both an inspectional and a scoring method.

The Greulich and Pyle Atlas ('59) was used with the inspectional method to obtain a skeletal age in years. The scoring method of TANNER, WHITEHOUSE AND HEALEY provided a total bone score which on conversion gave a skeletal age in years. The repeat assessments were compared with those obtained from the initial series for each subject.

## Series 2

To determine the effect of hand position on the rating of skeletal maturation, two left hand and wrist roentgenograms were obtained for the same group of 25 Caucasoids as above. On the first film the hand was in the position of rest; on the other the thumb was rotated. A standardized technique was used for each roentgenogram.

The hand was said to be in the rest position when it was held straight with the fingers separated and the thumb in a natural degree of rotation with the axis making an angle of $30^{o}$ with the first finger. The palm was pressed slightly downwards on the film.

The hand was said to be in the rotated thumb position when it was held straight and held flat against the film with the thumb rotated as much as possible.

## Series 3

To determine the effect of wrist position on skeletal assessment, three left hand and wrist roentgenograms were obtained for each of six patients registered in the Dental Department, The University of Adelaide. The films were obtained with the forearm in three separate positions:

1. forearm flat on the table;
2. forearm at $45^{o}$ to the wrist;
3. forearm almost at right angles to the wrist.

Series 4

To determine the effect of rotation of the thumb on the measurement of the ulna metacarpophalangeal sesamoid of the thumb, the diameter was recorded on two separate occasions for both the 'thumb-rest' and 'thumb-rotated' positions. Measurements were made to the nearest 0.5 mm with Wild calipers*.

(2) Ossification Events in Hand and Wrist Roentgenograms

Errors arose from two main sources: the field methods and the recording methods. Field method errors included those caused by difficulties in positioning the subject's hand and forearm on the film and movement of the subject's hand during exposure of the film. Recording method errors included those caused by difficulties in visualizing radiographic changes and the manner of measuring the diameter of the ulna metacarpophalangeal sesamoid of the thumb.

Ossification Events

Ossification events were recorded for all subjects by the same observer on two separate occasions. The time interval between determinations was approximately one month. Statistical analysis was made of the differences between determinations by means of the computer. When a discrepancy between the two observations of an ossification event was disclosed, a third determination was made.

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* Manufactured by Heerbrugg, Switzerland.

(3) Lateral Cephalometric Roentgenograms

The various sources of errors that occur in roentgenographic cephalometry have been reported by many researchers including ADAMS ('40), BJÖRK ('47), FRANKLIN ('52), THORNE ('53), WERNER ('55), NEVAKARI ('56), TALLGREN ('57), SARNÄS ('57), LYSELL and FILIPSSON ('58), HATTON and GRAINGER ('58), BROADWAY, HEALY and POYTON ('62). BJÖRK and SOLOW ('62) and BARRETT et al. ('63a). All these studies indicate that the errors involved are small and unlikely to affect results to any great extent. As roentgenographic cephalometry provides the only method of studying craniofacial structures thoroughly in living subjects, it is an extremely valuable tool in research providing results are interpreted carefully.

Errors arose from two sources: field methods and measuring methods. Field method errors included those caused by difficulties in positioning subjects in the cephalostat , difficulties in registering the intercuspal position, movement of subjects during exposure and errors in projection. Measurement errors included those caused by difficulties in locating reference points and reference lines and those caused by inaccuracies in the measuring instrument and in the reading of the recorded dimension.

Field method errors have previously been investigated by BROWN ('65) and found to be small. In order to determine the magnitude of measurement errors 50 lateral head roentgenograms were selected at random and all variables were measured on each film by the same observer, approximately one month after the completion of the first determination. The differences between two determinations were analysed and expressed as the mean of the difference (M.diff), the standard deviation of the differences (S.D. diff), and the error of the mean differences ( $\epsilon$M diff). The following formulae were used to determine the error statistics:

$$\text{M diff} = \frac{\Sigma\, d}{n}$$

$$\text{S.D. diff} = \sqrt{\frac{\Sigma(d - \text{M diff})^2}{n - 1}}$$

$$\epsilon\text{M diff} = \frac{\text{S.D. diff}}{\sqrt{n}}$$

where d = difference between two determinations,

n = number of double determinations.

In addition the method of Dahlberg ('40) was used to compute the standard deviation of a single determination ($S.D._s$) according to:

$$S.D._s = \sqrt{\frac{\Sigma\, d^2}{2n}}$$

where 2n = number of single determinations.

Student's "t-test" was used to determine the probability that a mean difference differed significantly from zero, thereby indicating a systematic discrepancy between the two determinations. For the test, the 5% and 1% probability levels were used and the mean differences were designated significant at the 5% level and significant at the 1% level respectively. The value of t was calculated according to the equation:

$$t = \frac{M\ diff}{\Sigma\ M\ diff}$$

The extent to which the variability due to experimental error affected the observed variance was indicated by using the generality that component parts of a variance can be summed to equal the total variance.

Thus:

$$S_1^{\ 2} = S_t^{\ 2} + S_e^{\ 2}$$

where $S_1^{\ 2}$ = observed variance from sample as determined from the original values. This value includes variance due to measurement error.

$S_t^{\ 2}$ = estimate of the true sample variance

$S_e^{\ 2}$ = variance due to measurement error, termed error variance in this study. This value is determined as $SD_s^{\ 2}$

where $S.D._s = \sqrt{\frac{\Sigma\ d^2}{2n}}$

The error variance was then expressed as a percentage of the observed variance.

## Results

Skeletal Age and Sesamoid*

Table 5 shows the basic descriptive statistics (mean, error of the mean, standard deviation, minimum and maximum) for the Caucasoid group and Table 6 for the Aboriginal group. Comparisons of the variables listed below were recorded for both groups separately. Analyses are listed in Tables 7 and 8.

Skeletal age - Atlas method (hand in rest position)

Skeletal age - Atlas method (hand in rotated position)

Round bone score - T/W (Tanner - Whitehouse method) (hand in rest position)

Long bone score - T/W method (hand in rest position)

Total bone score - T/W method (hand in rest position)

Skeletal age - T/W method (hand in rest position)

Round bone score - T/W method (hand in rotated position)

Long bone score - T/W method (hand in rotated position)

Total bone score - T/W method (hand in rotated position)

Skeletal age - T/W method (hand in rotated position)

Diameter of the metacarpophalangeal sesamoid of the thumb.

Significant differences were found between the inspectional and scoring method for both groups ($p < 0.01$). The Aborigines showed a significant difference between chronological age and skeletal age using the Atlas method ($p < 0.01$).

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* In this and following sections the Tanner-Whitehouse method for skeletal rating is indicated by the abbreviation T/W

Comparison of all other variables showed no significant difference. These results are summarized in Table 9.

## Ossification Events in Hand and Wrist Roentgenograms

A total of 1,257 double determinations were made on 419 hand and wrist roentgenograms. The differences between determinations were expressed as misclassifications. Table 10 shows the percentage of subjects with misclassification of either the pisiform, hamate or sesamoid bones.

## Lateral Cephalometric Roentgenograms

A total of 500 double determinations were made on 50 lateral head roentgenograms. The results showing the mean differences, the standard error of the mean differences and the standard deviation of single determination as well as variance (error) and per cent variance (error) for each variable are shown in Table 11.

TABLE 5. Determinations of skeletal age, round bone scores, long bone scores and sesamoid diameter made from hand and wrist roentgenograms of 25 Caucasoids. Ages recorded in decimal years, sesamoid diameter in mm.

| Variable | Mean | ε(M) | s | Min | Max |
|---|---|---|---|---|---|
| Chronological Age | 13.5 | 0.48 | 2.4 | 9.7 | 19.6 |
| Skeletal Age | | | | | |
| Atlas Method-Rest. | | | | | |
| Determination 1 | 13.2 | 0.56 | 2.8 | 8.0 | 19.0 |
| 2 | 13.2 | 0.58 | 2.9 | 7.5 | 19.0 |
| Skeletal Age | | | | | |
| Atlas Method-Rotate | | | | | |
| Determination 1 | 13.2 | 0.58 | 2.9 | 7.5 | 19.0 |
| 2 | 13.2 | 0.56 | 2.8 | 8.0 | 19.0 |
| Round Bone Score | | | | | |
| Rest | | | | | |
| Determination 1 | 351.8 | 30.70 | 153.5 | 125.0 | 500.0 |
| 2 | 352.1 | 30.10 | 150.3 | 119.0 | 500.0 |
| Long Bone Score | | | | | |
| Rest | | | | | |
| Determination 1 | 366.6 | 26.60 | 133.1 | 134.0 | 500.0 |
| 2 | 370.7 | 24.60 | 123.0 | 154.0 | 500.0 |
| Total Bone Score | | | | | |
| Rest | | | | | |
| Determination 1 | 718.4 | 56.20 | 280.8 | 259.0 | 1000.0 |
| 2 | 762.8 | 73.50 | 367.4 | 277.0 | 998.0 |
| Skeletal Age | | | | | |
| T/W Method - Rest | | | | | |
| Determination 1 | 13.7 | 0.63 | 3.2 | 8.0 | 19.0 |
| 2 | 13.8 | 0.58 | 2.9 | 8.5 | 19.0 |

TABLE 5 (continued).

| Variable | Mean | ε(M) | s | Min | Max |
|---|---|---|---|---|---|
| Round Bone Score | | | | | |
| Rest | | | | | |
| Determination 1 | 351.8 | 30.70 | 153.3 | 125.0 | 500.0 |
| Rotate | 352.1 | 30.10 | 150.3 | 119.0 | 500.0 |
| Long Bone Score | | | | | |
| Rest | | | | | |
| Determination 1 | 366.6 | 26.60 | 133.1 | 134.0 | 500.0 |
| Rotate | 375.0 | 24.10 | 120.4 | 158.0 | 500.0 |
| Total Bone Score | | | | | |
| Rest | | | | | |
| Determination 1 | 718.4 | 56.20 | 280.8 | 259.0 | 1000.0 |
| Rotate | 727.1 | 53.10 | 265.6 | 277.0 | 1000.0 |
| Skeletal Age | | | | | |
| T/W Method | | | | | |
| Rotate | 13.8 | 0.58 | 2.9 | 8.7 | 19.0 |
| Sesamoid Diameter | | | | | |
| Determination 1 | 4.8 | 0.28 | 1.1 | 2.0 | 6.5 |
| 2 | 4.8 | 0.28 | 1.1 | 2.0 | 6.5 |

TABLE 6. Determinations of skeletal age, round bone scores, long bone scores and sesamoid diameter made from hand and wrist roentgenograms of 25 Aborigines. Ages recorded in decimal years, sesamoid diameter in mm.

| Variable | Mean | ε(M) | s | Min | Max |
|---|---|---|---|---|---|
| Chronological Age | 12.9 | 0.24 | 1.2 | 10.9 | 15.2 |
| Skeletal Age | | | | | |
| Atlas Method | | | | | |
| Determination 1 | 12.2 | 0.32 | 1.6 | 9.4 | 15.0 |
| 2 | 12.1 | 0.31 | 1.6 | 10.0 | 15.0 |
| Round Bone Score | | | | | |
| Determination 1 | 346.5 | 24.10 | 120.4 | 180.0 | 500.0 |
| 2 | 328.1 | 21.90 | 109.4 | 177.0 | 500.0 |
| Long Bone Score | | | | | |
| Determination 1 | 326.1 | 19.00 | 94.8 | 218.0 | 496.0 |
| 2 | 307.6 | 17.70 | 88.7 | 196.0 | 496.0 |
| Total Bone Score | | | | | |
| Determination 1 | 672.6 | 41.60 | 208.0 | 412.0 | 947.0 |
| 2 | 635.7 | 38.10 | 190.5 | 405.0 | 967.0 |
| Skeletal Age | | | | | |
| T/W Method | | | | | |
| Determination 1 | 13.3 | 0.29 | 1.5 | 10.1 | 15.8 |
| 2 | 13.0 | 0.27 | 1.3 | 10.4 | 15.4 |
| Sesamoid Diameter | | | | | |
| Determination 1 | 3.1 | 0.27 | 0.9 | 2.0 | 4.5 |
| 2 | 3.1 | 0.28 | 1.0 | 2.0 | 4.5 |

TABLE 7. Analysis of differences between double determinations of hand and wrist roentgenograms of 25 Caucasoids. Ages recorded in decimal years, sesamoid diameter in mm.

| Variable | Mean | ε(M) | s | Min | Max | T-value |
|---|---|---|---|---|---|---|
| Atlas-Rest | | | | | | |
| Determination 1-2 | 0.0 | 0.04 | 0.2 | -0.5 | -0.5 | 0.49 |
| Atlas-Rotate | | | | | | |
| Determination 1-2 | -0.1 | 0.04 | 0.2 | -0.5 | 0.3 | -1.31 |
| Atlas | | | | | | |
| Rest 1-Rotate 1 | 0.0 | 0.04 | 0.2 | -0.5 | 0.5 | 0.23 |
| Chronological Age-Skeletal Age | | | | | | |
| Atlas Rest 1 | 0.4 | 0.24 | 1.2 | -1.6 | 3.2 | 1.48 |
| Chronological Age-Skeletal Age | | | | | | |
| Atlas Rotate 1 | 0.4 | 0.26 | 1.3 | -1.6 | 3.7 | 1.42 |
| Round Bone Score | | | | | | |
| Determination 1-2 | -0.3 | 6.60 | 33.0 | -80.0 | 111.0 | -0.05 |
| Long Bone Score | | | | | | |
| Determination 1-2 | -4.1 | 2.70 | 13.5 | -33.0 | 16.0 | -1.51 |
| Total Bone Score | | | | | | |
| Determination 1-2 | -44.4 | 40.50 | 202.5 | -18.0 | 111.0 | -1.10 |
| Skeletal Age-T/W | | | | | | |
| Determination 1-2 | -0.1 | 0.09 | 0.5 | -1.2 | 1.1 | -0.79 |

+ Mean difference significant at the $p < 0.01$ level

TABLE 7 (continued)

| Variable | Mean | ε(M) | s | Min | Max | T-value |
|---|---|---|---|---|---|---|
| Round Bone Score<br>Rest 1-Rotate | -0.3 | 6.60 | 33.0 | -80.0 | 111.0 | -0.05 |
| Long Bone Score<br>Rest 1-Rotate | -8.3 | 3.10 | 15.6 | -47.0 | 16.0 | -2.67 |
| Total Bone Score<br>Rest 1-Rotate | -8.7 | 7.20 | 36.0 | -100.0 | 98.0 | -1.20 |
| Skeletal Age-T/W<br>Rest 1-Rotate | -0.1 | 0.10 | 0.5 | -1.2 | 1.1 | -1.38 |
| Chronological Age-<br>Skeletal Age<br>T/W Rest 1 | -0.2 | 0.31 | 1.6 | -3.1 | 4.1 | -0.55 |
| Chronological Age-<br>Skeletal Age<br>T/W Rotate | -0.3 | 0.28 | 1.4 | -3.1 | 3.4 | -1.10 |
| Skeletal Age<br>Atlas Rest 1-<br>T/W Rest 1 | -0.5 | 0.15 | 0.8 | -2.3 | 0.8 | -3.49+ |
| Skeletal Age<br>Atlas Rest 1<br>T/W Rotate | -0.7 | 0.15 | 0.7 | -2.3 | 1.0 | -4.54+ |
| Sesamoid Diameter<br>Determination 1-2 | 0.0 | 0.00 | 0.0 | 0.0 | 0.0 | 0.0 |

+ Mean difference significant at the $p < 0.01$ level

TABLE 8. Analysis of differences between double determinations of hand and wrist roentgenograms of 25 Aborigines. Ages recorded in decimal years, sesamoid diameter in mm.

| Variable | Mean | ε(M) | s | Min | Max | T-value |
|---|---|---|---|---|---|---|
| Skeletal Age Atlas Method | | | | | | |
| Determination 1-2 | 0.1 | 0.06 | 0.3 | -0.6 | 0.5 | 1.35 |
| Chronological Age-Skeletal Age | | | | | | |
| Atlas Method 1 | 0.7 | 0.20 | 1.0 | -1.0 | 2.3 | 3.47+ |
| Round Bone Score | | | | | | |
| Determination 1-2 | 18.4 | 12.50 | 62.6 | -70.0 | 144.0 | 1.47 |
| Long Bone Score | | | | | | |
| Determination 1-2 | 18.6 | 7.20 | 35.8 | -87.0 | 91.0 | 2.59 |
| Total Bone Score | | | | | | |
| Determination 1-2 | 37.0 | 14.30 | 71.7 | -59.0 | 194.0 | 2.58 |
| Skeletal Age T/W Method | | | | | | |
| Determination 1-2 | 0.3 | 0.12 | 0.6 | -0.5 | 1.6 | 2.42 |
| Chronological Age-Skeletal Age | | | | | | |
| T/W Determination 1 | -0.4 | 0.22 | 1.1 | -2.7 | 1.2 | -1.56 |
| Skeletal Age | | | | | | |
| Atlas 1-T/W 1 | -1.0 | 0.16 | 0.8 | -2.4 | 1.0 | 6.46+ |
| Sesamoid Diameter | | | | | | |
| Determination 1-2 | 0.0 | 0.07 | 0.3 | -0.5 | 0.5 | 0.56 |

+ Mean difference significant at the $p < 0.01$ level.

TABLE 9. Comparison of chronological age and skeletal age determined by the Atlas and Tanner-Whitehouse Methods. Differences in mean ages recorded in decimal years.

| Variable | Caucasian M M(diff) | Caucasian F ε(M diff) | Aboriginal M M(diff) | Aboriginal F ε(M diff) |
|---|---|---|---|---|
| Differences between Atlas Rest 1 T/W Rest 1 | -0.5+ | 0.15 | -1.0+ | 0.16 |
| Differences between Atlas Rest 1 T/W-Rotate | -0.7+ | 0.15 | - | - |
| Differences between Chronol. Age Atlas Rest 1 | 0.4 | 0.24 | 0.7+ | 0.20 |
| Chronol. Age T/W Rest | -0.2 | 0.31 | -0.4 | 0.22 |
| Chronol. Age T/W Rotate | -0.3 | 0.28 | - | - |

+ Mean difference significant at the $p < 0.01$ level

TABLE 10. Misclassification of ossification events on hand and wrist roentgenograms.

| Ossification Event | | Number of Determinations | Number of Misclassifications | Percentage Misclassifications |
|---|---|---|---|---|
| Pisiform | | | | |
| | M | 253 | 5 | 1.98 |
| | F | 166 | 4 | 2.41 |
| | M + F | 419 | 9 | 2.15 |
| Hamate | | | | |
| | M | 253 | 15 | 5.93 |
| | F | 166 | 9 | 5.42 |
| | M + F | 419 | 24 | 5.73 |
| Sesamoid | | | | |
| | M | 253 | 0 | 0.00 |
| | F | 166 | 0 | 0.00 |
| | M + F | 419 | 0 | 0.00 |

TABLE 11. Analysis of the differences in mm between double determinations of the 10 linear measurements on 50 lateral cephalometric roentgenograms. The observed variance, $S_1^2$ the error variance, $S_e^2$ and the error variance per cent $S_e^2 \times 100/S_1^2$ are shown .

| Variable | Mean | ε(M) | $S_1^2$ | $S_e^2$ | $S_e^2 \times 100/S_1^2$ |
|---|---|---|---|---|---|
| n-s | -0.07 | 0.03 | 6.59 | 0.03 | 0.47 |
| pm-sp | 0.03 | 0.11 | 8.86 | 0.31 | 3.51 |
| pg-ar | 0.02 | 0.05 | 36.43 | 0.07 | 0.20 |
| pg-go | -0.13 | 0.08 | 30.21 | 0.18 | 0.59 |
| ar-go | 0.21* | 0.09 | 14.10 | 0.20 | 1.42 |
| n-gn | 0.14 | 0.08 | 47.17 | 0.13 | 0.28 |
| n-sp | 0.15 | 0.14 | 13.30 | 0.49 | 3.67 |
| id-gn | 0.06 | 0.05 | 10.63 | 0.06 | 0.54 |
| pr-id | -0.12* | 0.06 | 2.72 | 0.08 | 2.86 |
| pm-s | -0.14 | 0.09 | 11.48 | 0.20 | 1.69 |

* M diff. differs from zero at the 5 per cent probability level.

## DISCUSSION

### (1) Skeletal Age and Sesamoid Diameter

For Caucasoids and Aborigines there was a significant difference ($p < 0.01$) between skeletal ages assessed by the Atlas and T/W methods, using films obtained with the hand and wrist in the rest position. In Aborigines, the T/W age determination was greater than the Atlas age determination by 1.0 years and in Caucasians by 0.5 years. With the thumb rotated, a greater difference (0.7 years) was revealed between the two methods for Caucasians. The differences shown in skeletal age assessments determined by both methods support the findings of FRY ('68) and ROCHE and JOHNSON ('69).

Rotation of the thumb did not affect the skeletal age assessment determined by the Atlas method (mean difference between determinations 0.0 years). Using the T/W method, rotation of the thumb revealed a slightly greater difference (mean difference between determinations 0.1 years). However, the difference between the two assessment methods with the hand in the rotated position was 0.7 years compared to 0.5 years with the thumb in the rest position. Therefore, strict attention must be paid to the thumb position when obtaining hand and wrist roentgenograms employing the T/W method for skeletal age assessment.

Skeletal age determination using the Atlas method, with the hand and wrist in the rest position was on the average 0.7 years earlier than chronological age in Aborigines and 0.4 years earlier in Caucasoids. The difference was significant in Aborigines only. The slightly retarded skeletal development revealed in Aborigines supports the studies of ABBIE and ADEY ('53).

It was more difficult to visualize the radiographic changes consistently in Aborigines than in Caucasians. In Aborigines, the difference between first and second determinations using the Atlas method was 0.1 years compared to a 0.3 years difference between determinations using the T/W method. Double determinations of long bone scores showed a significant difference ($p < 0.05$) in Aborigines. This was possibly the result of varying hand positions.

The Atlas method would seem to be more reliable where a non-standard hand and wrist roentgenographic technique is used, as in the field studies at Yuendumu in Central Australia. The Atlas method is quicker and involves a general assessment. Although it leads to different assessments than those films determined by inspecting and scoring many bones with the T/W method, the Atlas method appears to be the technique of choice with the available material.

Until standards of hand and wrist ossification are available for Aborigines it is necessary to use those standards developed for Caucasoid children. Moreover, at the present time there is no information on the differences between hand and wrist ossification in Aborigines and Caucasoids over the age range represented by the subjects of this study. However,ratings made for Aborigines according to the Atlas Method, should lead to consistent results particularly if the time scale is based on "Caucasoid equivalent" years.

(2) Ossification Events

The per cent misclassification of ossification events (pisiform - 2.15%, hamate - 5.73%, and sesamoid - 0.00%) indicate the consistency in visualizing these changes on hand and wrist roentgenograms. The minor difficulty in visualizing the two stages in the ossification of the hook of the hamate seems to relate to the interpretation of stage 1.

(3) Lateral Cephalometric Roentgenograms

The range of the mean differences between the double determinations of ten linear dimensions on 50 lateral cephalometric roentgenograms was -0.14 to +0.21 mm. Employment of the "t test" revealed that the mean difference of the variables ramus height (0.21 ± 0.09) and middle face height (0.12 ± 0.06) differed from zero at the $p = 0.05$ level. None of the means displayed deviations from zero significant at the 1% level.

Comparison of the mean difference of ramus height (0.21) with its mean value (42.81) and of middle face height (0.12) with its mean value (25.67), illustrates that the experimental error will not seriously affect sample mean values.

The standard deviation of a single determination was used to assess the degree to which the measurement errors affected estimates of a population variance or standard deviation. For example, using summation of variances and the anlysis of variance for the dimension upper face height it can be seen that the unbiased sample variance closely approximates the observed variance from the sample as the maximum error variance of 0.49 represents only 3.67% of the observed variance. The minimum error variance per cent of 0.20% occurred in the dimension total mandibular length. This shows that the experimental errors did not greatly affect variance estimates.

## CONCLUSIONS

Varying hand positions can affect a skeletal age assessment. In the investigation of technique for rating skeletal age, the Atlas Method was shown to provide more consistent assessments than the Tanner/Whitehouse scoring system. The Greulich Pyle Atlas was, therefore, used for all skeletal age assessments in the present study.

The appearance of the selected ossification events can be accurately visualized and there seems to be little doubt than an observer after some experience, could consistently assess such clear cut events.

It has also been shown that the experimental errors in the measurement of serial cephalometric roentgenograms did not seriously affect the results. As a consequence, the methods employed can be justified.

CHAPTER IV

# RATING OF SKELETAL MATURITY

Serial hand and wrist roentgenograms of each subject included in the study were used to derive estimates of skeletal age and to obtain the age-at-appearance of selected ossification events in the carpus. All ossification events studied appeared, on the average, around puberty; furthermore, they could be recognized readily on the roentgenograms. These two criteria were applied in the study.

## METHOD

"Caucasoid equivalent" skeletal age ratings were made on each hand and wrist roentgenogram employing the inspectional method of GREULICH and PYLE ('59). The film to be assessed was compared with the standard of the same sex and nearest chronologic age in the Atlas. It was then compared with adjacent standards until a standard which superficially resembled it was found.

A more detailed comparison was then made of the individual bones and epiphyses in the following order: the distal ends of the radius and ulna, the carpals (order was capitate, hamate, triquetral, pisiform, lunate, navicular, trapezium and trapezoid), the metacarpals, and finally the phalanges. If an individual bone in the film was at the same stage of development as the corresponding bone in the standard selected for detailed comparison, it was given the skeletal rating of that standard. However, when the bone was retarded or advanced, comparison was made with adjacent standards respectively. If the comparison indicated the bones showed the same degree of development, then the skeletal rating of that standard was recorded. If a bone was intermediate between the standard selected for detailed comparison and the adjacent standard it was given an intermediate skeletal rating between the two standards.

The ossification events studied, defined in Chapter II, illustrated in Fig. 8 and listed in the Appendix C, were:

ossification of pisiform

ossification of hook of hamate - stages 1 and 2

ossification and size of the sesamoid of the thumb

The time of onset of these ossification events was recorded when the first radiographic changes in ossification could be clearly visualized. The size of the sesamoid of the thumb was determined by measuring its greatest diameter to the nearest 0.5 mm with calipers. All assessments were entered directly onto skeletal maturation form 7, from which the age-at-appearance for the various ossification events was selected.

SESAMOID SIZE CLASSIFICATION

Stage 1 - maximum diameter not exceeding 1.5 mm

Stage 2 - maximum diameter not exceeding 2.5 mm

Stage 3 - maximum diameter exceeding 2.5 mm

AGE-AT-APPEARANCE OF OSSIFICATION EVENTS

Criteria for selection

1. Age was taken as the mid-point of the year in which each event appeared, that is, between adjacent observations, one year apart. However, because the visits to Yuendumu in 1961 and 1962 were made in the months of January and August respectively, the time interval of 1.6 years was accepted in this instance.
2. The ossification event appeared between adjacent records, that is, the film taken previously to the one which showed the appearance of the event revealed no evidence of ossification.
3. The ossification event was clearly visible.

For example, if an event was not present on a record taken at age 11.4 years but present on the next record taken at 12.4 years, the onset of the event was recorded as 11.9 years.

All assessments made on the hand and wrist roentgenograms were transferred to punched cards. These cards were identified as data card 1. Statistical analyses of the data were carried out by computer.

The mean age-at-appearance of the ossification events were compared with the only available data for Australian Aborigines (ABBIE and ADEY '53b). Comparisons were also made with standards reported by various authors for Caucasoid children.

## RESULTS

The results are summarized in Table 12 which lists the mean, the error of the mean, the standard deviation and the range of observations for chronological and skeletal ages-at-appearance for the various ossification events and sesamoid stages. Male and female differences in the age-at-appearance of the ossification events studied are illustrated in Fig. 10 which was drawn from mean values for both sexes.

## DISCUSSION

Analysis of mean values revealed that the earliest events to be seen on serial hand and wrist roentgenograms were the initial ossification of the pisiform and the hook of the hamate. Hamate-stage 1 appeared at 10.6 years in females and 12.2 years in males; and the age-at-appearance of the pisiform was 10.5 years in females and 12.6 years in males. Ossification in the adductor sesamoid of the thumb, which was the last event to be seen occurred at 11.2 years in females and 13.5 years in males.

All ossification events occurred earlier in females than in males. The greatest sex difference in the timing of ossification events was 2.3 years for both hamate-stage 2 and the sesamoid. A similar sex difference for the sesamoid is given by GREULICH and PYLE ('59), GARN and ROHMANN ('62) and BJÖRK and HELM ('67). The smallest sex dif-

TABLE 12. Time of appearance of ossification events on serial hand and wrist roentgenograms are recorded in years for 52 males and 36 females.

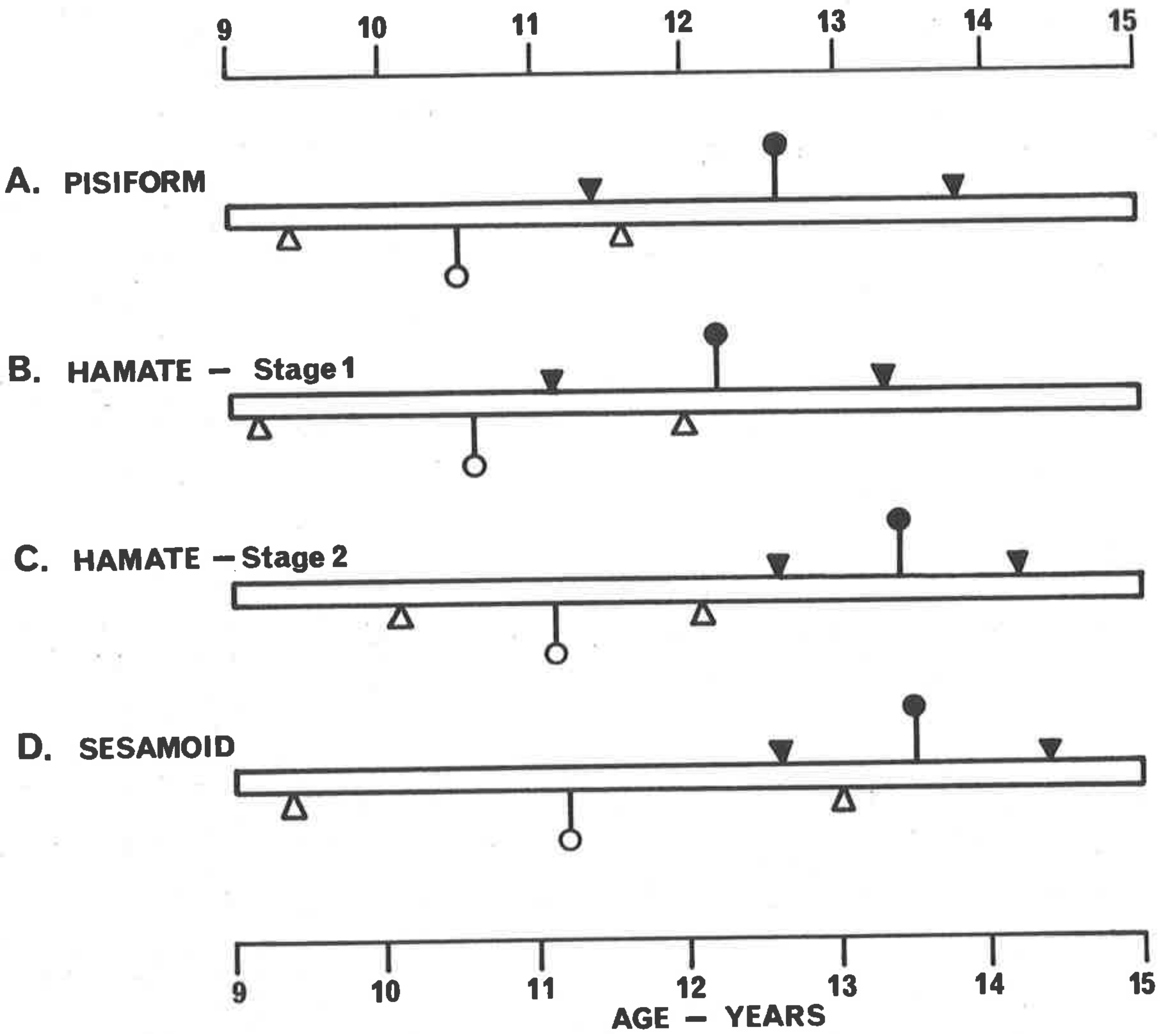
| Variable | | Mean | ε(M) | s | Min | Max | n |
|---|---|---|---|---|---|---|---|
| PISIFORM | | | | | | | |
| Chron.Age | M | 12.6 | 0.19 | 1.2 | 9.6 | 15.1 | 43 |
| | F | 10.5 | 0.21 | 1.1 | 8.9 | 12.9 | 25 |
| Skelet. Age | M | 11.9 | 0.13 | 0.8 | 9.5 | 13.3 | 43 |
| | F | 9.8 | 0.17 | 0.9 | 7.8 | 11.8 | 25 |
| HAMATE-STAGE 1 | | | | | | | |
| Chron.Age | M | 12.2 | 0.21 | 1.1 | 10.6 | 14.2 | 29 |
| | F | 10.6 | 0.34 | 1.4 | 8.9 | 14.9 | 18 |
| Skelet.Age | M | 11.5 | 0.16 | 0.8 | 9.5 | 13.3 | 29 |
| | F | 9.9 | 0.20 | 0.9 | 8.9 | 12.3 | 18 |
| HAMATE-STAGE 2 | | | | | | | |
| Chron.Age | M | 13.4 | 0.14 | 0.8 | 11.6 | 16.1 | 37 |
| | F | 11.1 | 0.21 | 1.0 | 9.8 | 13.4 | 23 |
| Skelet.Age | M | 12.8 | 0.10 | 0.6 | 11.3 | 13.6 | 37 |
| | F | 10.7 | 0.11 | 0.6 | 9.7 | 12.0 | 23 |

Age was recorded as the mid-point of the year in which each event appeared, i.e. between adjacent observations, 1 year apart.

TABLE 12 (continued)

| Variable | | Mean | ε(M) | s | Min | Max | n |
|---|---|---|---|---|---|---|---|
| SESAMOID | | | | | | | |
| Chron.Age | M | 13.5 | 0.14 | 0.9 | 10.9 | 16.1 | 43 |
| | F | 11.2 | 0.23 | 1.8 | 9.2 | 13.9 | 26 |
| Skelet.Age | M | 12.7 | 0.08 | 0.5 | 11.3 | 13.6 | 43 |
| | F | 10.6 | 0.12 | 0.6 | 9.2 | 12.0 | 26 |
| SESAMOID-STAGE 1 | | | | | | | |
| Chron.Age | M | 12.9 | 0.55 | 1.2 | 10.9 | 13.9 | 5 |
| | F | 11.2 | 0.31 | 1.0 | 9.8 | 13.4 | 10 |
| Skelet.Age | M | 12.2 | 0.18 | 0.4 | 11.6 | 12.5 | 5 |
| | F | 10.6 | 0.14 | 0.5 | 9.7 | 11.0 | 10 |
| SESAMOID-STAGE 2 | | | | | | | |
| Chron.Age | M | 13.4 | 0.18 | 0.8 | 11.6 | 14.9 | 19 |
| | F | 11.7 | 0.31 | 1.2 | 9.8 | 13.9 | 14 |
| Skelet.Age | M | 12.8 | 0.11 | 0.5 | 12.0 | 13.6 | 19 |
| | F | 10.9 | 0.20 | 0.5 | 10.0 | 12.0 | 14 |
| SESAMOID-STAGE 3 | | | | | | | |
| Chron.Age | M | 13.8 | 0.20 | 1.0 | 11.9 | 16.1 | 25 |
| | F | 12.1 | 0.41 | 1.7 | 9.2 | 14.9 | 17 |
| Skelet.Age | M | 13.0 | 0.12 | 0.6 | 11.3 | 13.9 | 25 |
| | F | 11.5 | 0.24 | 1.0 | 9.2 | 13.0 | 17 |

Age was recorded as the mid-point of the year in which each event appeared, i.e. between adjacent observations, 1 year apart.



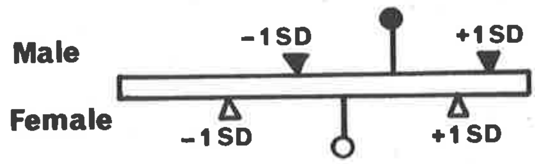




Fig. 10. Mean age-at-appearance of ossification events

ference in timing of an event was recorded as 1.6 years for hamate-stage 1. This value approximates that of ABBIE and ADEY ('53b) and GREULICH and PYLE ('59).

The pisiform ossified 2.1 years earlier in the females of the group. ABBIE and ADEY ('53b) stated that the age-at-appearance of the pisiform in females was on the average 3 - 4 years ahead of males. They also stated that in males it appeared at about the same time as the metacarpophalangeal sesamoid of the thumb. In the present study, ossification of the pisiform was recorded 0.9 years before the sesamoid ossified. The age-at-appearance for the pisiform given by GREULICH and PYLE ('59) and GRAY ('58) indicates an earlier ossification in Caucasoids.

Initial ossification of the hook of the hamate occurred at 10.6 years in females and 12.2 years in males. These values closely approximate those given by ABBIE and ADEY (11.0 years in females and 12.0 years in males) and GREULICH and PYLE (10.5 years in females and 12.0 years in males).

JOSEPH ('51) found the metacarpophalangeal sesamoids of the thumb ossify in all persons. His investigation on a group of Indians and Africans suggested that there was no racial difference in the incidence of the sesamoids of the thumb. In Aboriginal males the sesamoid appeared at 13.5 years, which is approximately 1 year later than North American males (GREULICH and PYLE '59, GARN and ROHMANN '62). However, the sesamoid appeared slightly later (3 months) than the age estimated in Danish males by BJÖRK and HELM ('67). In Aboriginal females, the sesamoid appeared at 11.2 years, which is approximately midway between time of appearance of the sesamoid in North American and Danish girls.

Table 13 compares the age-at-appearance of the various ossification events given by a number of authors for Caucasoids with the findings for Aborigines.

TABLE 13. Time of appearance of ossification events reported by various authors (age in years).

| Ossification Event | Group | Investigator | Females | Males |
|---|---|---|---|---|
| Pisiform | Nth.American Whites | Greulich & Pyle('59) | 8.3 | 10.0 |
| | Not stated | Gray('58) | 9.0-10.0 | 12.0 |
| | Australian Aborigines | Abbie & Adey('53b) | 10.0-11.0 | <14.0 |
| | Australian Aborigines | Present Study | 10.5 | 12.6 |
| Hook of Hamate | Nth.American Whites | | 10.5 | 12.0 |
| | Australian Aborigines | Abbie & Adey('53b) | 11.0 | 12.0 |
| | Australian Aborigines | Present Study | 10.6 | 12.2 |
| Sesamoid | Nth.American Whites | Greulich & Pyle('59) | 10.5 | 12.5 |
| | Nth.American Whites | Garn & Rohmann('62) | 10.5 | 12.6 |
| | Danish | Björk & Helm('67) | 11.5 | 12.6 |
| | Australian Aborigines | Present Study | 11.2 | 13.5 |

## SUMMARY

1. The age-at-appearance for various ossification events have been recorded from serial hand and wrist roentgenograms of 52 male and 36 female Aborigines.
2. Females displayed earlier ossification times than males. This pattern was similar to that reported for other ethnic groups.
3. In general, the ossification events studied occurred slightly later in Aborigines than in Caucasoids.

CHAPTER V

# GROWTH VELOCITIES AROUND ADOLESCENCE

Individual variation in growth and development results from the interplay between genetic and environmental influences. It can be difficult to investigate the relative importance of hereditary and environment in growth variations in human populations. However, the role of environmental factors as determinants of ethnic group differences in growth has been discussed by WEINER and THAMBIPILLAI ('52), GREULICH ('57) and MASSE and HUNT ('63).

A short term environmental disturbance will often produce a temporary variation in growth (HIERNAUX, '68). In most instances, the depression caused by acute starvation or disease is soon compensated by an acceleration in growth (TANNER, '63). However, long-term growth retardation results when starvation occurs soon after birth (HIERNAUX, '65).

Most Aborigines breast feed their children for at least 12 months and in many instances for two years (ELLIOTT, MAXWELL, KNEEBONE and KIRKE, '69). The mean birth weight for Aborigines was lower than that for White Australians by 1 lb 12 oz in males and 1 lb 9 oz in females (KETTLE, '66). KETTLE also observed that during the first six months of post natal life, Aborigines appeared to grow more rapidly than white Australians, but after this time the increments were much smaller and so their mean weight was always less.

ELLIOTT and others ('69) showed that the lactose content of breast milk in Aborigines decreased markedly after the sixth month of lactation, and breast milk production did not increase with the age of the suckling. Furthermore, the same authors suggested that the quality and quantity of breast milk were possibly responsible for the diminished nutrition that occurred in the second six months of life. In Japanese subjects TAKAHASKI ('66) showed a high association between adult stature and the consumption of milk and eggs during childhood.

Supplementary feeding of infants and small children has been carried out for many years by trained nurses at the Government Settlements (CAMPBELL and BARRETT, '53; KETTLE, '66). ABBIE ('70) has found little evidence of gross malnutrition in Aboriginal children living at various Settlements in Australia. Furthermore, BROWN and BARRETT ('70), using serial height measurements obtained at Yuendumu, found few differences in average height attained between Aboriginal children and British children after age five or thereabouts. However, MAXWELL and ELLIOTT ('69), using stature, weight and other selected body measurements, interpreted their results to indicate a high incidence of malnutrition in the Aboriginal subjects examined, compared with Caucasoid standards.

KIRKE ('69) found that Aboriginal children, fed and cared for in much the same way as white Australian children reveal almost identical growth patterns to Caucasoids. The physical proportions of children are similar for Aborigines and Europeans up to approximately six years when a sudden extension of the inferior extremities occurs (ABBIE, '57). The proportions in Aborigines at this age are close to those of a

European child aged 12 years (ABBIE, '58). However, after this age growth seems to proceed at about the same rate in both ethnic groups.

Investigations on the rate of growth in the facial skeleton have been reviewed in Chapter I. It seems appropriate to emphasize that in most studies the variables are measured across two or more bones. HOWELLS ('69) stated that *"measurements, especially of the cranium, which allows the location of larger numbers of anatomical points, have tended to become bound by tradition."* He suggested that attention be given to ensure better and more descriptive methods in any investigation. As a consequence, variables were selected in the present study to describe the rate of growth in each unit of the nasomaxillary complex as accurately and simply as possible.

## METHODS

### STATURE

Standing height was measured using a specially designed anthropometer with the subject standing without shoes, his back against the vertical rod (Fig.5). A relaxed body position was attained by having the subject focus on some distant object. The horizontal arm of the anthropometer was lowered until it made firm contact with the crown of the head without pressure. No attempt was made to elevate the head by applying upward pressure at the mastoid region as is done in some techniques of stature measurements.

FACIAL VARIABLES

The variables studied (Fig. 9), defined in Chapter 2 and listed in the Appendix C, were:

| | |
|---|---|
| Anterior cranial base length | n - s |
| Maxillary jaw base length | pm - sp |
| Total mandibular length | pg - ar |
| Mandibular corpus length | pg - go |
| Mandibular ramus height | ar - go |
| Morphological face height | n - gn |
| Upper face height | n - sp |
| Mandibular face height | id - gn |
| Middle face height | pr - id |
| Posterior upper face height | pm - s |

For more consistent location of reference points, each of the series of films for a subject was studied before locating the reference points. All films were measured on a fixed viewing table in the orthodontic department of The University of Adelaide. The viewing table is constructed so that the light intensity can be varied. Sliding screens eliminate extraneous light from areas on the film under inspection. These two facilities allowed more consistent location of the various reference points. At times a small hand magnifying glass was also used to assist in the location of certain points which were difficult to visualize. Whenever a bilateral landmark appeared as a double image on the lateral head roentgenogram, the reference point was located as the mid-point of the left and right images.

All films were covered with an overlay for protection and all variables were measured directly on the films with a dial gauge vernier scale (Fig. 11). These measurements were directed onto skeletal maturation form 7. All observations were later transferred to punched cards for computer analysis.

The velocity for height attained was computed from the differences in height at two consecutive times. This was repeated for all observations for a subject with the velocity recorded as occurring at the mid-point of the time interval between two consecutive observations. For example, if the height of a subject was 145.5 cm at age 13.8 years and 154.8 cm at age 14.8 years then the velocity for the interval was computed as 9.3 cm/year occurring at 14.3 years. The peak velocity was taken to be the maximum of the individual velocities calculated for each interval between adjacent observations, providing it met certain criteria. Peak velocities for facial dimensions were recorded in the same way. The actual form of the computer output for the growth analyses is shown in Appendix D.

Calculations of the magnitude and time of maximum growth velocity were accepted only if the following criteria were met:

1. Maximum velocity occurred between adjacent observations, preferably at one year interval;
2. Maximum velocity occurred between adjacent velocity calculations, that is, there should be a velocity before and after the maximum;
3. A minimum of three velocities, that is, four observations were available;

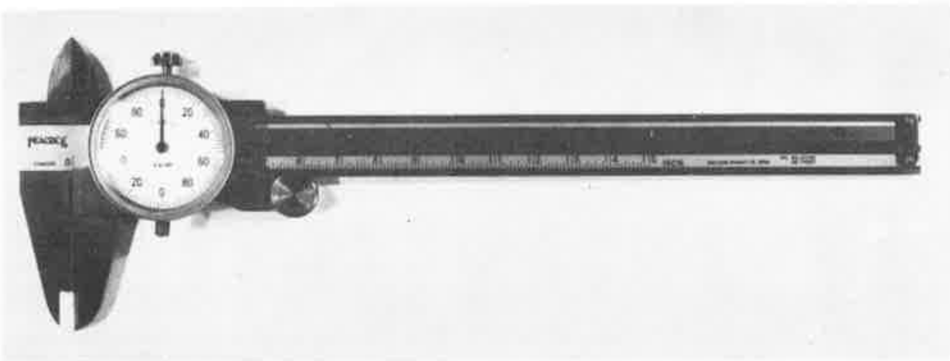


Fig. 11. Dial gauge vernier caliper

4. Maximum velocity occurred within the expected puberal age range or it was clear cut;
5. Maximum velocity exceeded other recorded velocities by a value equal to the approximate measurement error. For stature it was taken to be 0.5 cm; for facial dimensions 0.5 mm.

Peak velocities which satisfied the above criteria were recorded independently by two observers for all subjects. Comparisons of selected peak velocities were made and any differences were noted and discussed by both observers before final acceptance.

## RESULTS

The results are summarized in Tables 14 - 17 which list the mean, the error of the mean, the standard deviation and the range of observations for peak velocity in stature and the facial dimensions studied. Male and female differences in the magnitude and time of peak velocity in growth are illustrated in Figs. 12 and 13 which were drawn from mean values for both sexes.

## DISCUSSION

Peak velocity of stature at adolescence was 10.3 cm/year in males and 8.5 cm/year in females. The mean value in Aboriginal males was the same as that recorded for British males by TANNER, WHITEHOUSE and TAKAISHI ('66). However, the mean value for Aboriginal females was less than that for British females (9.1 cm/year, TANNER et al., '66).

TABLE 14. Timing (in years) and magnitude (cm/year) of peak velocity in stature in 50 males and 32 females.

| Variable | | Mean | ε(M) | s | Min | Max | n |
|---|---|---|---|---|---|---|---|
| Magnitude | | | | | | | |
| | M | 10.3 | 0.19 | 1.1 | 8.5 | 12.2 | 30 |
| | F | 8.5 | 0.24 | 1.0 | 6.8 | 11.4 | 18 |
| Chron.Age | | | | | | | |
| | M | 13.8 | 0.17 | 0.9 | 12.8 | 16.1 | 30 |
| | F | 11.8 | 0.28 | 1.2 | 9.9 | 14.4 | 18 |
| Skelet.Age | | | | | | | |
| | M | 13.0 | 0.12 | 0.6 | 11.3 | 13.8 | 27 |
| | F | 11.2 | 0.15 | 0.6 | 10.2 | 12.0 | 17 |

Age was recorded as the mid-point of the year during which peak velocity occurred, i.e. between adjacent observations, 1 year apart.

TABLE 15. Timing (in years) and magnitude (mm/year) of peak velocity in the anterior cranial base and maxilla in 50 males and 32 females.

| Variable | | Mean | ε(M) | s | Min | Max | n |
|---|---|---|---|---|---|---|---|
| Anterior cranial base length (n-s) | | | | | | | |
| Magnitude | M | 2.4 | 0.21 | 1.1 | 1.1 | 7.2 | 28 |
| | F | 1.7 | 0.12 | 0.6 | 0.9 | 3.0 | 23 |
| Chron.Age | M | 13.8 | 0.23 | 1.2 | 11.6 | 16.8 | 28 |
| | F | 12.2 | 0.25 | 1.2 | 9.8 | 14.4 | 23 |
| Skelet.Age | M | 13.1 | 0.21 | 1.0 | 11.3 | 15.1 | 23 |
| | F | 11.4 | 0.24 | 1.1 | 9.0 | 13.1 | 22 |
| Maxillary jaw base length (pm-sp) | | | | | | | |
| Magnitude | M | 2.9 | 0.26 | 1.2 | 1.0 | 6.4 | 20 |
| | F | 2.4 | 0.17 | 0.8 | 1.2 | 4.0 | 21 |
| Chron.Age | M | 13.5 | 0.29 | 1.3 | 10.7 | 15.8 | 20 |
| | F | 11.7 | 0.33 | 1.5 | 9.6 | 15.2 | 21 |
| Skelet.Age | M | 12.7 | 0.27 | 1.2 | 10.3 | 15.1 | 19 |
| | F | 11.2 | 0.28 | 1.3 | 8.9 | 14.4 | 21 |

Age was recorded as the mid-point of the year during which peak velocity occurred, i.e. between adjacent observations, 1 year apart.

TABLE 16. Timing (in years) and magnitude (mm/year) of peak velocity in the mandible in 50 males and 32 females.

| Variable | | Mean | ε(M) | s | Min | Max | n |
|---|---|---|---|---|---|---|---|
| Total length (pg-ar) | | | | | | | |
| Magnitude | M | 5.5 | 0.28 | 1.4 | 2.9 | 8.4 | 28 |
| | F | 4.8 | 0.24 | 1.1 | 2.7 | 7.0 | 21 |
| Chron.Age | M | 13.8 | 0.20 | 1.1 | 11.6 | 16.8 | 28 |
| | F | 12.0 | 0.25 | 1.1 | 9.9 | 14.2 | 21 |
| Skelet.Age | M | 13.0 | 0.20 | 0.9 | 10.3 | 15.1 | 23 |
| | F | 11.6 | 0.23 | 1.1 | 10.0 | 14.0 | 21 |
| Corpus length (pg-go) | | | | | | | |
| Magnitude | M | 3.8 | 0.16 | 0.9 | 2.3 | 5.6 | 29 |
| | F | 3.1 | 0.17 | 0.8 | 1.9 | 4.7 | 22 |
| Chron.Age | M | 13.9 | 0.18 | 1.0 | 12.6 | 16.8 | 29 |
| | F | 11.9 | 0.25 | 1.2 | 9.6 | 14.8 | 21 |
| Skelet.Age | M | 13.1 | 0.16 | 0.8 | 11.3 | 15.1 | 25 |
| | F | 11.5 | 0.31 | 1.4 | 7.6 | 15.0 | 21 |
| Ramus height (ar-go) | | | | | | | |
| Magnitude | M | 4.1 | 0.24 | 1.2 | 2.6 | 6.9 | 26 |
| | F | 3.6 | 0.24 | 1.1 | 1.6 | 5.6 | 21 |
| Chron.Age | M | 13.9 | 0.27 | 1.4 | 11.2 | 16.8 | 26 |
| | F | 12.5 | 0.35 | 1.6 | 9.6 | 17.1 | 21 |
| Skelet.Age | M | 13.2 | 0.25 | 1.1 | 11.3 | 16.4 | 19 |
| | F | 11.8 | 0.28 | 1.3 | 10.0 | 14.0 | 20 |

Age was recorded as the mid-point of the year during which peak velocity occurred, i.e. between adjacent observations, 1 year apart.

TABLE 17. Timing (in years) and magnitude (mm/year) of peak velocity in face height in 50 males and 32 females.

| Variable | | Mean | ε(M) | s | Min | Max | n |
|---|---|---|---|---|---|---|---|
| Morphological Face height (n-gn) | | | | | | | |
| Magnitude | M | 5.4 | 0.36 | 1.9 | 3.0 | 12.3 | 27 |
| | F | 4.4 | 0.23 | 1.0 | 2.5 | 6.0 | 16 |
| Chron.Age | M | 13.8 | 0.26 | 1.4 | 11.3 | 16.8 | 27 |
| | F | 12.2 | 0.32 | 1.3 | 10.0 | 15.2 | 16 |
| Skelet.Age | M | 12.9 | 0.24 | 1.1 | 10.5 | 16.4 | 23 |
| | F | 11.7 | 0.21 | 0.8 | 10.5 | 13.1 | 16 |
| Upper face height (n-sp) | | | | | | | |
| Magnitude | M | 3.1 | 0.25 | 1.3 | 1.5 | 6.9 | 26 |
| | F | 3.2 | 0.28 | 1.1 | 1.3 | 5.2 | 15 |
| Chronol.Age | M | 13.0 | 0.36 | 1.8 | 9.5 | 16.1 | 26 |
| | F | 12.1 | 0.47 | 1.8 | 9.8 | 15.0 | 15 |
| Skelet.Age | M | 12.6 | 0.35 | 1.7 | 9.3 | 16.4 | 24 |
| | F | 11.1 | 0.43 | 1.6 | 8.9 | 15.0 | 13 |
| Mandibular face height (id-gn) | | | | | | | |
| Magnitude | M | 2.0 | 0.11 | 0.5 | 1.2 | 3.2 | 26 |
| | F | 1.8 | 0.14 | 0.6 | 1.0 | 3.2 | 16 |
| Chron.Age | M | 13.8 | 0.23 | 1.2 | 10.6 | 16.1 | 26 |
| | F | 12.7 | 0.27 | 1.1 | 10.5 | 14.4 | 16 |
| Skelet.Age | M | 12.9 | 0.21 | 1.0 | 10.3 | 14.5 | 22 |
| | F | 12.0 | 0.27 | 1.0 | 10.3 | 14.0 | 15 |

Age was recorded as the mid-point of the year in which each event appeared, i.e. between adjacent observations, 1 year apart.

TABLE 17 (continued).

| Variable | | Mean | ε(M) | s | Min | Max | n |
|---|---|---|---|---|---|---|---|
| Middle Face height (pr-id) | | | | | | | |
| Magnitude | M | 1.7 | 0.16 | 0.8 | 0.7 | 4.0 | 22 |
| | F | 1.5 | 0.22 | 0.8 | 0.7 | 3.6 | 13 |
| Chron.Age | M | 13.3 | 0.38 | 1.8 | 10.5 | 16.8 | 22 |
| | F | 12.6 | 0.35 | 1.3 | 10.9 | 15.1 | 13 |
| Skelet.Age | M | 12.6 | 0.41 | 1.7 | 10.5 | 17.3 | 17 |
| | F | 12.4 | 0.42 | 1.4 | 10.5 | 15.5 | 12 |
| Posterior upper face height (pm-s) | | | | | | | |
| Magnitude | M | 2.5 | 0.13 | 0.7 | 0.8 | 3.7 | 28 |
| | F | 2.1 | 0.15 | 0.7 | 1.0 | 3.7 | 23 |
| Chron.Age | M | 13.4 | 0.29 | 1.5 | 9.5 | 16.8 | 28 |
| | F | 12.1 | 0.25 | 1.2 | 9.6 | 14.4 | 23 |
| Skelet.Age | M | 12.6 | 0.25 | 1.2 | 9.5 | 14.5 | 24 |
| | F | 11.5 | 0.26 | 1.2 | 7.6 | 13.1 | 21 |

Age was recorded as the mid-point of the year during which peak velocity occurred, i.e. between adjacent observations, 1 year apart.

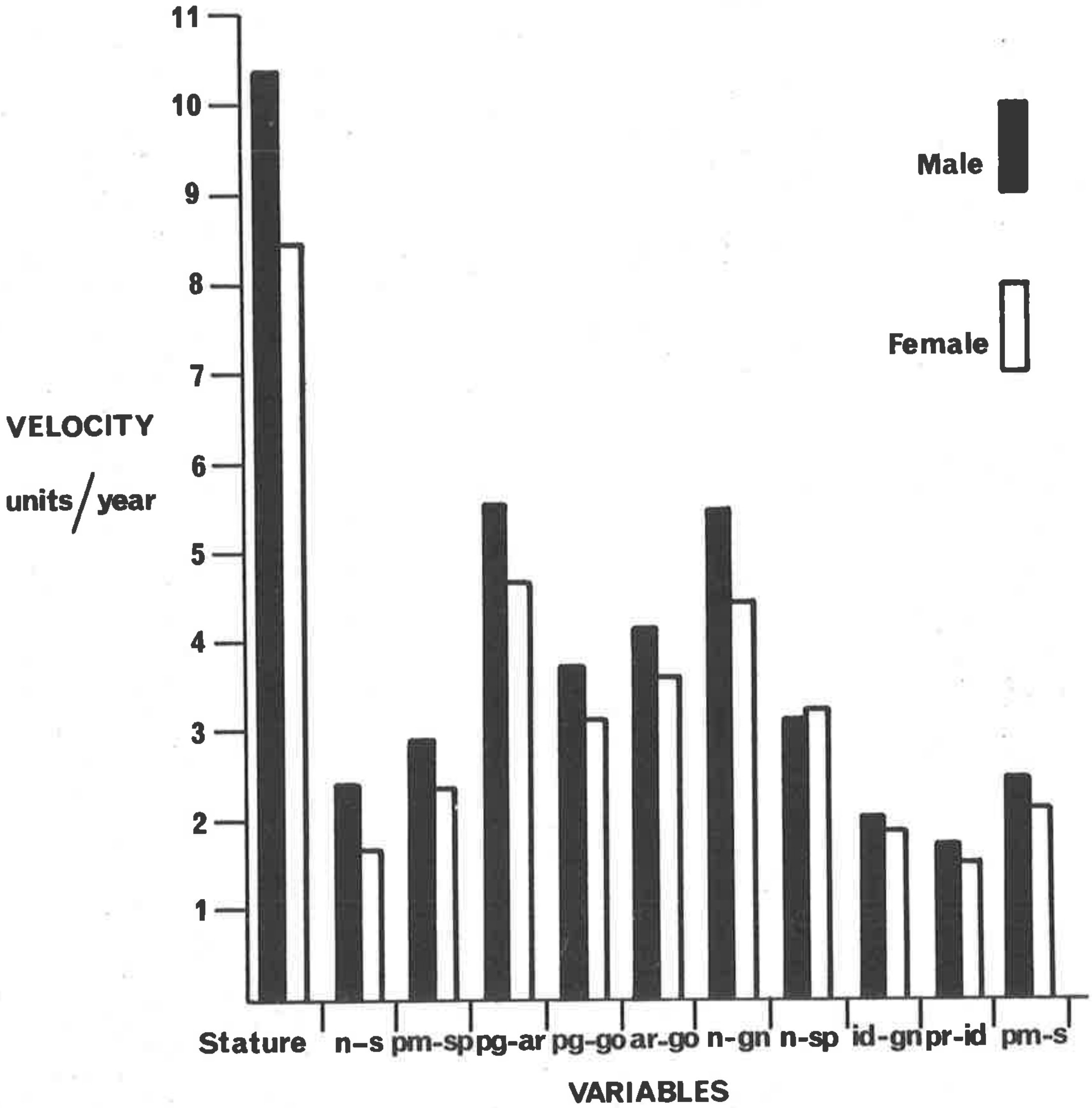



Fig. 12. Magnitude of mean values for peak velocity in stature and facial dimensions in males and females.

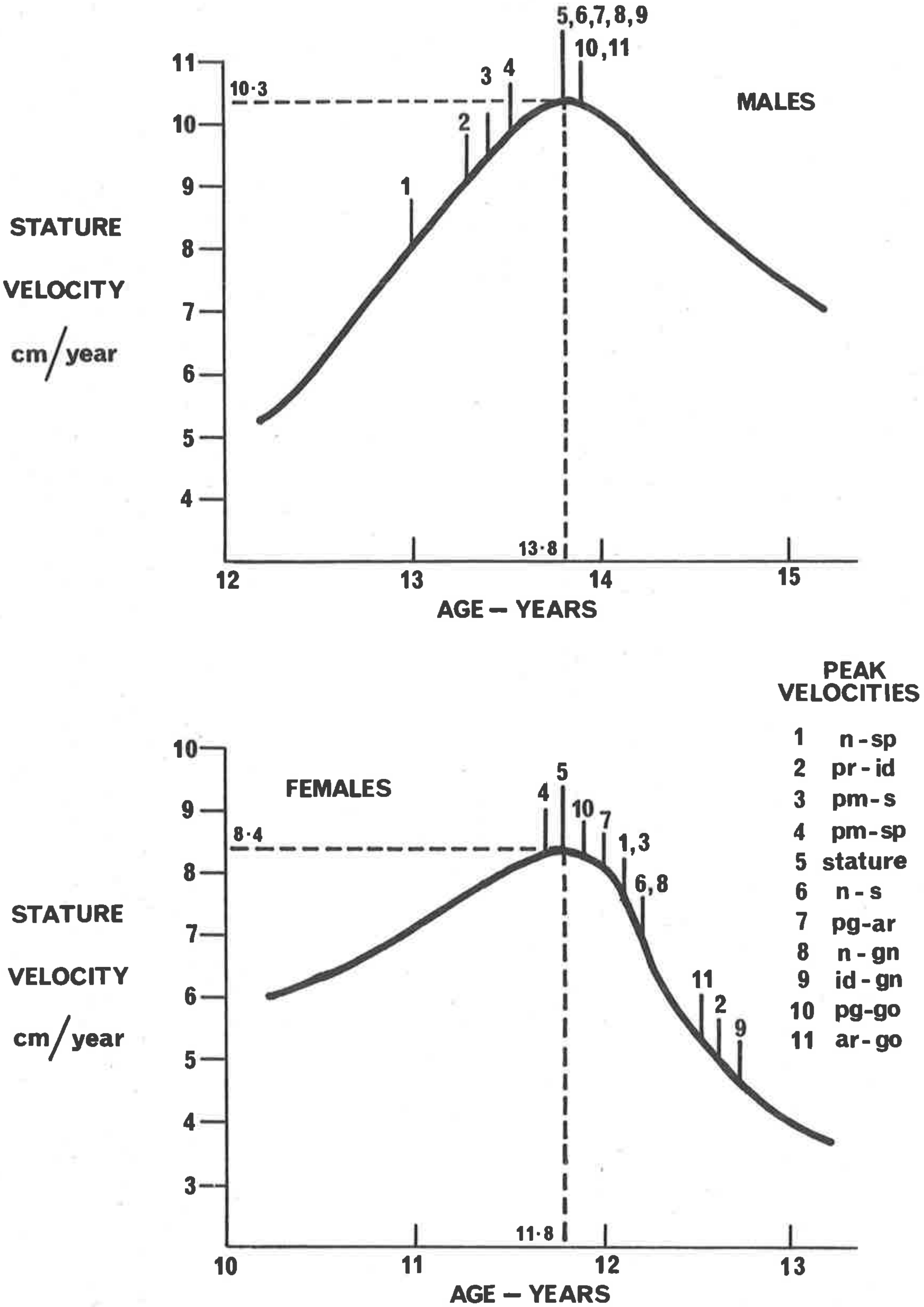



Fig. 13. Mean ages at peak velocity for facial dimensions marked on a stature curve for males and females.

The average ages at which peak velocity in stature was reached in Aboriginal children were 13.8 years for males and 11.8 years for females. These values are midway between those given by TANNER et al. ('66) and DEMING ('57) for British and North American children respectively. The sex difference in mean age at peak velocity was 2.0 years. This value corresponds to the sex difference of 2.0 years given by TANNER et al. ('66) and DEMING ('57) for the timing of peak stature velocity.

The maximum growth velocity of facial dimensions was greater in males than females, except for one variable, upper face height. Females reached their peak velocity in the face earlier than males. The maximum sex difference in the age at peak velocity was 2.0 years for the dimension mandibular body length and the minimum was 0.7 years for the dimension middle face height. The mean age for peak velocity in the maxilla was 11.7 years in females. This corresponds closely to the mean value of 11.5 years reported by SINGH and SAVARA ('66) for the time of maximum growth in the maxilla in females.

Maximum growth in the length of the maxilla occurred before peak velocity in stature in both males and females. The last event to occur in females was peak velocity in mandibular face height. This occurred on the average 0.9 years after peak velocity in stature. Peak velocities of facial height measurements in males occurred before peak velocity in stature, with one exception, morphological face height. Peak velocities of mandibular dimensions all occurred either at the same time or slightly after peak velocity in stature.

The reference point, gnathion, is influenced by the later mandibular growth. This is the most likely explanation for growth in morphological face height following the general pattern of mandibular growth. Maximum growth in the length of the mandible was almost coincident with maximum growth in stature for males and females. This finding is similar to that of HUNTER ('66) who studied Caucasoid children.

## SUMMARY

Methods used in this stature and facial growth study as well as those employed in calculating and selecting the time and magnitude of peak velocity have been described. Analysis of results revealed the following:

1. Males showed a greater peak velocity in stature than females but on the average, growth velocities in the facial skeleton were of similar value in males and females. Peak velocity occurred earlier in females both in stature and facial dimensions.
2. In females, peak velocity of most facial dimensions occurred after peak velocity in stature, whereas in males peak velocity of most facial height measurements occurred before and mandibular measurements occurred after peak statural velocity. Peak velocity of maxillary length occurred before peak velocity in stature in both males and females.

CHAPTER VI

# ASSOCIATIONS BETWEEN FACIAL GROWTH AND SKELETAL MATURATION

To assess the strength of relations between the age-at-appearance of ossification events and the timing and magnitude of peak velocity in stature and certain facial dimensions, coefficients of linear correlation were computed for all paired combinations of variables.

SOLOW ('66 p.75) states *"although a correlation analysis gives no information about causal relationships, it has generally been assumed in the interpretation of anthropological associations that the presence of a significant correlation indicates a biological co-ordination."* However, correlations between some variables may be biased if the variables share common reference points, reference lines or angles. This effect comes about because the variability of the common points used to determine the variables will be included in the variability of each variable, thus the co-variance increases between them. This form of correlation was referred to by SOLOW ('66 p.82) as "topographical", while correlations between variables not sharing common points or lines were termed "non-topographical".

PEARSON and DAVIN ('24) introduced the term, "spurious" correlations, in relation to variables that shared common components and those linear variables that "covered" each other. Variables measured on cephalometric roentgenograms are also subject to "spurious" co-ordination.

BROWN ('67) introduced the concept of "specious" associations between variables sharing common components, variables spanning adjacent anatomical regions, and variables sharing common reference points or lines. Thus, his use of the term "specious" included both previous terms mentioned - "spurious" and "topographical". He stressed that *"the presence of a "specious" co-ordination between two variables does not preclude the possibility of additional biological co-ordination; it means, however, that until more is known of the nature of anthropometric associations observed correlation values should be interpreted cautiously".*

CROXTON ('53 p.127) states that *"the presence of correlation between two sets of data does not necessarily mean that causation is present even though the correlation may be high".* Correlation may be present as a result of any one of the following conditions:

1. Correlation may be fortuitous;
2. One variable is the cause, although not necessarily the sole cause, of the other;
3. The two variables may be interdependent;
4. The two variables may be affected by the same cause.

GARN and SHAMIR ('58 p.84) warned against attaching too great biological relationship between age-associated events, because many developmental events are essentially irreversible and occur in a fairly definite sequence. The same authors give as an example a study that reported moderate to high correlations between third molar formation stages and either chronological or physiological age ($r = 0.73$). Before agreeing with the previous statement they state that *"one need only note that the correlation between age at the beginning of third molar formation and menarche is essentially zero"*.

BJÖRK and SOLOW ('62) found that correlation coefficients between variables having common reference points which are marked on radiographs, will be biased. The increase in the correlation co-efficient is due to the fact that the errors involved when marking the points are also correlated. They found that measuring procedures will also affect the value of a correlation coefficient.

The matrix of correlation coefficients between the 58 variables included correlations among the chronological and skeletal age-at-appearance of ossification events, and the magnitude, chronological and skeletal age-at-peak velocity in stature and certain facial dimensions. These variables are listed in Appendix C.

To clarify interpretation of the 1,653 coefficients computed, the matrix has been partitioned into segments which are presented in the following tables. Coefficients were arbitrarily classified as follows: "high" relation, $r \geq 0.80$; "moderate" relation, $0.80 > r \geq 0.40$; "low" relation, $r < 0.40$, disregarding sign and according to GARN ('58).

## RESULTS

Tables 18 - 27 list the coefficients of correlation determined for males and females separately. Average coefficients for males and females combined were determined by Z - transformation of the coefficients for each group using the method of FISHER ('58 p.204). These trans-formed coefficients are also shown in the Tables.

Coefficients significantly differing from zero at the 5% and the 1% levels are marked * and ** respectively. Coefficients that differed significantly between sexes are marked ++.

TABLE 18. Correlations between time of appearance of ossification events observed on serial hand and wrist roentgenograms and timing and magnitude of peak velocity in stature in 50 males and 32 females. ψ §

| OSSIFICATION EVENT | | STATURE VELOCITY | | |
|---|---|---|---|---|
| | | Magnitude | Chron.Age | Skelet.Age |
| PISIFORM | | | | |
| Chron. Age | M | .06 | .51* | .20 |
| | F | -.27 | .75** | .14 |
| | M + F | -.07 | .62** | .18 |
| Skelet. Age | M | .04 | .28 | .46* |
| | F | -.29 | .20 | .40 |
| | M + F | -.09 | .25 | .44** |
| HAMATE-STAGE 1 | | | | |
| Chron. Age | M | .18 | .19 | -.11 |
| | F | -.22 | .71** | .06 |
| | M + F | .00 | .46** | -.04 |
| Skelet. Age | M | -.04 | -.06 | .49 |
| | F | -.23 | .48 | .12 |
| | M + F | -.12 | .19 | .33 |
| HAMATE-Stage 2 | | | | |
| Chron. Age | M | -.25 | .75** | .15 |
| | F | -.09 | .83** | .30 |
| | M + F | -.20 | .78** | .21 |
| Skelet. Age | M | -.21 | .10 | .41 |
| | F | .18 | .35 | .28 |
| | M + F | -.07 | .19 | .36* |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

ψ In this and the following tables coefficients differing from zero at the 5% and the 1% level were arbitrarily classified as follows: "high" relation, $r \geq 0.80$; "moderate" relation, $0.80 > r \geq 0.40$; "low" relation, $r < 0.40$, disregarding sign and according to GARN ('58).

§ Although records were obtained from 50 males and 32 females, there were many missing observations in the series. Consequently, the correlation coefficients reported in this and subsequent tables were derived from the available observations, which in most instances numbered less than the total.

TABLE 18 (continued)

| OSSIFICATION EVENT | | STATURE VELOCITY | | |
|---|---|---|---|---|
| | | Magnitude | Chron.Age | Skelet.Age |
| **SESAMOID** | | | | |
| Chron.Age | M | -.14 | .84** | .20 |
| | F | -.09 | .85** | .16 |
| | M + F | -.12 | .84** | .19 |
| Skelet.Age | M | -.10 | .52** | .65** |
| | F | .12 | .47 | .15 |
| | M + F | -.02 | .51** | .50** |
| **SESAMOID-Stage 1** | | | | |
| Chron.Age | M | Insufficient paired observations | | |
| | F | -.38 | .89* | .35 |
| | M + F | Insufficient paired observations | | |
| Skelet.Age | M | Insufficient paired observations | | |
| | F | -.07 | .63 | .23 |
| | M + F | Insufficient paired observations | | |
| **SESAMOID-Stage 2** | | | | |
| Chron.Age | M | -.43 | .92** | .81** ++ |
| | F | .64 ++ | .82** | -.11 |
| | M + F | -.03 | .89** | .57** |
| Skelet.Age | M | -.27 | .41 | .87** |
| | F | .40 | .08 | .46 |
| | M + F | -.03 | .30 | .78** |
| **SESAMOID-Stage 3** | | | | |
| Chron.Age | M | -.17 | .80** | .13 |
| | F | -.25 | .84** | .21 |
| | M + F | -.21 | .82** | .17 |
| Skelet.Age | M | -.06 | .41 | .47* |
| | F | -.26 | .55* | .20 |
| | M + F | -.15 | .47** | .36* |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 19(a) Correlations between timing and magnitude of peak velocity in facial dimensions and stature in 50 males and 32 females.

| FACIAL DIMENSION | | STATURE | | |
|---|---|---|---|---|
| | | Magnitude | Chron.Age | Skelet.Age |
| **ANTERIOR CRANIAL BASE LENGTH** | | | | |
| (n-s) | | | | |
| Magnitude | M | -.07 | .31 | .32 |
| | F | .28 | .17 | .04 |
| | M + F | .08 | .25 | .20 |
| Chron. Age | M | -.38 | .87** | .45 |
| | F | .12 | .76** | .26 |
| | M + F | -.18 | .83** | .37* |
| Skelet. Age | M | .03 | .34 | .53* |
| | F | .04 | -.02 | .27 |
| | M + F | .04 | .18 | .42* |
| **MAXILLARY JAW BASE LENGTH** | | | | |
| (pm-sp) | | | | |
| Magnitude | M | -.41 | -.05 | -.09 |
| | F | .54++ | -.03 | -.26 |
| | M + F | .00 | -.04 | -.17 |
| Chron. Age | M | .11 | .32 | .46 |
| | F | .13 | .78** | .20 |
| | M + F | .12 | .56** | .34 |
| Skelet. Age | M | .27 | -.03 | .38 |
| | F | .13 | .43 | .02 |
| | M + F | .21 | .19 | .22 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 19(b)

| FACIAL DIMENSION | | STATURE | | |
|---|---|---|---|---|
| | | Magnitude | Chron. Age | Skelet. Age |
| TOTAL LENGTH OF MANDIBLE (pg-ar) | | | | |
| Magnitude | M | .29 | -.31 | .12 |
| | F | .27 | -.31 | -.39 |
| | M + F | .28 | -.31 | -.06 |
| Chron. Age | M | -.35 | .78** | .56** |
| | F | -.40 | .79** | .22 |
| | M + F | -.36* | .78** | .46** |
| Skelet. Age | M | .05 | .28 | .72** |
| | F | -.51 | .50 | .38 |
| | M + F | -.19 | .37* | .62** |
| CORPUS LENGTH OF MANDIBLE (pg-go) | | | | |
| Magnitude | M | .25 | -.39 | -.25 |
| | F | .39 | -.14 | -.06 |
| | M + F | .30 | -.30 | -.18 |
| Chron. Age | M | -.49* | .88** | .56** |
| | F | -.51* | .67** | .43 |
| | M + F | -.50** | .83** | .51** |
| Skelet. Age | M | -.13 | .49* | .87** ++ |
| | F | -.34 | -.09 | .31 |
| | M + F | -.22 | .28 | .73** |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 19(c)

| FACIAL DIMENSION | | STATURE | | |
|---|---|---|---|---|
| | | Magnitude | Chron. Age | Skelet.Age |
| RAMUS HEIGHT OF MANDIBLE | | | | |
| (ar-go) | | | | |
| Magnitude | M | .27 | -.25 | -.02 |
| | F | .20 | -.28 | .20 |
| | M + F | .24 | -.26 | .07 |
| Chron.Age | M | -.11 | .13 | -.01 |
| | F | -.02 | .64* | .08 |
| | M + F | -.08 | .35* | .02 |
| Skelet. Age | M | .15 | -.10 | .28 |
| | F | -.41 | -.31 | .05 |
| | M + F | -.13 | -.20 | .18 |
| MORPHOLOGICAL FACE HEIGHT | | | | |
| (n-gn) | | | | |
| Magnitude | M | .23 | -.12 | -.16 |
| | F | -.14 | -.38 | .15 |
| | M + F | .11 | -.21 | -.06 |
| Chron. Age | M | -.37 | .83** | .43 |
| | F | .34 | .84** | .12 |
| | M + F | -.15 | .84** | .34 |
| Skelet. Age | M | .04 | .39 | .50* |
| | F | -.06 | .39 | .25 |
| | M + F | .00 | .39* | .42* |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 19(d)

| FACIAL DIMENSION | | STATURE | | | |
|---|---|---|---|---|---|
| | | Magnitude | Chron.Age | Skelet.Age | |
| UPPER FACE HEIGHT | | | | | |
| (n-sp) | | | | | |
| Magnitude | M | .31 | -.05 | -.22 | |
| | F | .30 | -.16 | -.21 | |
| | M + F | .31 | -.08 | -.21 | |
| Chron. Age | M | -.06 | .31 | .15 | |
| | F | .09 | .34 | .21 | |
| | M + F | -.01 | .32 | .17 | |
| Skelet. Age | M | -.22 | .35 | .37 | |
| | F | .44 | .11 | .45 | |
| | M + F | -.02 | .28 | .40* | |
| MANDIBULAR FACE HEIGHT | | | | | |
| (id-gn) | | | | | |
| Magnitude | M | .09 | -.04 | .28 | |
| | F | -.62* | .08 | .32 | |
| | M + F | -.15 | -.01 | .29 | |
| Chron. Age | M | -.59** | .90** | .69** | |
| | F | .15 | .72* | -.22 | ++ |
| | M + F | -.42* | .86** | .50** | |
| Skelet. Age | M | -.21 | .45 | .80** | |
| | F | .09 | -.14 | -.01 | ++ |
| | M + F | -.11 | .27 | .64** | |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 19(e)

| FACIAL DIMENSION | | STATURE | | |
|---|---|---|---|---|
| | | Magnitude | Chron.Age | Skelet.Age |
| MIDDLE FACE HEIGHT | | | | |
| (pr-id) | | | | |
| Magnitude | M | -.12 | .22 | .02 |
| | F | -.12 | .27 | .79* |
| | M + F | -.12 | .23 | .28 |
| Chron. Age | M | -.09 | .39 | .40 |
| | F | .22 | .56 | -.08 |
| | M + F | -.01 | .44* | .29 |
| Skelet. Age | M | .37 | .04 | .35 |
| | F | -.31 | -.26 | -.27 |
| | M + F | .19 | -.05 | .17 |
| POSTERIOR UPPER FACE HEIGHT | | | | |
| (pm-s) | | | | |
| Magnitude | M | -.11 | .30 | .11 |
| | F | .14 | .05 | .06 |
| | M + F | .00 | .20 | .09 |
| Chron. Age | M | -.40 | .80** | .44 |
| | F | .25 | .76** | .15 |
| | M + F | -.14 | .79** | .31 |
| Skelet. Age | M | -.06 | .35 | .53* |
| | F | .26 | -.17 | .10 |
| | M + F | .09 | .12 | .34 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 20(a) Correlations between timing and magnitude of peak velocity in facial dimensions and time of appearance of the hook of hamate observed on serial hand and wrist roentgenograms in 50 males and 32 females.

| FACIAL DIMENSION | | HAMATE-STAGE 1 | | HAMATE-STAGE 2 | |
|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| (n-s) | | | | | |
| Magnitude | M | -.21 | .00 | -.06 | -.17 |
| | F | .36 | .28 | .04 | .04 |
| | M + F | .06 | .13 | -.02 | -.09 |
| Chron.Age | M | .01 | -.02 | .39 | -.03 |
| | F | .49 | .25 | .51* | .06 |
| | M + F | .25 | .11 | .44** | .01 |
| Skelet.Age | M | .13 | .29 | .20 | .29 |
| | F | -.11 | -.06 | .01 | -.01 |
| | M + F | .01 | .11 | .11 | .15 |
| (pm-sp) | | | | | |
| Magnitude | M | -.50 | -.12 | -.22 | .19 |
| | F | -.24 | -.44 | .29 | .43 |
| | M + F | -.36 | -.31 | .05 | .32 |
| Chron.Age | M | .71* | .38 | .44 | .20 |
| | F | .68* | .15 | .71** | .17 |
| | M + F | .69** | .26 | .60** | .19 |
| Skelet.Age | M | .61* | .60 | .15 | .37 |
| | F | .41 | .05 | .28 | -.03 |
| | M + F | .51* | .32 | .22 | .16 |
| (pg-ar) | | | | | |
| Magnitude | M | -.41 | -.13 | -.25 | .09 |
| | F | -.17 | -.39 | -.18 | -.08 |
| | M + F | -.32 | -.23 | -.22 | .02 |
| Chron.Age | M | .30 | .24 | .39 | .01 |
| | F | .74** | .35 | .51* | .09 |
| | M + F | .50** | .28 | .44** | .04 |
| Skelet.Age | M | .40 | .66* | .15 | .45++ |
| | F | .34 | .02 | -.03 | -.25 |
| | M + F | .37 | .41 | .07 | .15 |

* Coefficients significant at p < .05

** Coefficients significant at p < .01

++ Difference between males and females significant at p < .01

TABLE 20(b)

| FACIAL DIMENSION | | HAMATE-STAGE 1 | | HAMATE-STAGE 2 | |
|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| (pg-go) | | | | | |
| Magnitude | M | .20 | -.02 | -.10 | .01 |
| | F | -.25 | -.48 | .10 | .14 |
| | M + F | .00 | -.23 | -.02 | .06 |
| Chron.Age | M | .30 | .06 | .57** | .07 |
| | F | .75** | .48 | .55* | .11 |
| | M + F | .54** | .26 | .57** | .08 |
| Skelet.Age | M | -.10 | .49 | .36 | .52* ++ |
| | F | .02 | .30 | -.30 | -.20 |
| | M + F | -.04 | .40* | .08 | .24 |
| (ar-go) | | | | | |
| Magnitude | M | .24 | .20 | -.05 | .22 ++ |
| | F | -.37 | -.25 | -.45 | -.51 |
| | M + F | -.03 | .01 | -.22 | -.08 |
| Chron.Age | M | .16 | -.08 | -.13 | -.37 |
| | F | .64* | .40 | .51 | .13 |
| | M + F | .40 | .14 | .13 | -.18 |
| Skelet.Age | M | -.03 | .30 | -.30 | -.09 |
| | F | -.28 | -.29 | -.23 | -.21 |
| | M + F | -.19 | -.08 | -.26 | -.14 |
| (n-gn) | | | | | |
| Magnitude | M | .09 | -.13 | .00 | -.08 |
| | F | -.54 | -.45 | -.16 | .15 |
| | M + F | -.15 | -.25 | -.05 | -.02 |
| Chron.Age | M | .30 | .05 | .58** | .07 |
| | F | .76* | .50 | .78** | .08 |
| | M + F | .50* | .22 | .65** | .07 |
| Skelet.Age | M | .05 | .20 | .16 | .21 |
| | F | .21 | -.11 | .59 | -.02 |
| | M + F | .11 | .08 | .32 | .13 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 20(c)

| FACIAL DIMENSION | | HAMATE-STAGE 1 | | HAMATE-STAGE 2 | |
|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| (n-sp) | | | | | |
| Magnitude | M | -.21 | -.19 | .08 | .19 |
| | F | -.38 | -.44 | .08 | .14 |
| | M + F | -.27 | -.28 | .08 | .17 |
| Chron.Age | M | .23 | -.16 | .38 | .01 |
| | F | .32 | .35 | .31 | .30 |
| | M + F | .26 | .02 | .36* | .12 |
| Skelet.Age | M | -.04 | -.10 | .30 | .16 |
| | F | .18 | .57 | .10 | .42 |
| | M + F | .03 | .13 | .24 | .24 |
| (id-gn) | | | | | |
| Magnitude | M | -.02 | .28 | -.01 | .40 |
| | F | -.36 | -.50 | .09 | -.04 |
| | M + F | -.14 | -.01 | .20 | .29 |
| Chron.Age | M | .17 | .38 | .66** | .32 |
| | F | .56 | .19 | .75* | .33 |
| | M + F | .32 | .32 | .69** | .32 |
| Skelet.Age | M | .28 | .52 | .25 | .43 |
| | F | -.23 | -.29 | .20 | .16 |
| | M + F | -.08 | .22 | .23 | .36 |
| (pr-id) | | | | | |
| Magnitude | M | .42 | -.03 | .13 | -.09 |
| | F | -.39 | -.10 | -.06 | .04 |
| | M + F | .26 | -.04 | .07 | -.05 |
| Chron.Age | M | .27 | .08 | .38 | .08 |
| | F | .92* | .58 | .25 | -.07 |
| | M + F | .50* | .20 | .34 | .03 |
| Skelet.Age | M | .10 | .13 | .10 | .16 |
| | F | -.07 | .25 | -.40 | -.40 |
| | M + F | .05 | .17 | -.11 | -.08 |

* Coefficients significant at p < .05

** Coefficients significant at p < .01

++ Difference between males and females significant at p < .01

TABLE 20(d)

| FACIAL DIMENSION | | HAMATE-STAGE 1 | | HAMATE-STAGE 2 | |
|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| (pm-s) | | | | | |
| Magnitude | M | .04 | .10 | .03 | .06 |
| | F | -.14 | -.40 | .19 | .07 |
| | M + F | -.04 | -.12 | .10 | .07 |
| Chron.Age | M | -.12 | -.28 | .59** | .16 |
| | F | .58* | .17 | .79** | .36 |
| | M + F | .21 | -.09 | .68** | .24 |
| Skelet.Age | M | -.18 | .03 | .27 | .45 |
| | F | -.67* | -.66* | .04 | .09 |
| | M + F | -.43* | -.32 | .17 | .30 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 21(a). Correlations between timing and magnitude of peak velocity in facial dimensions and time of appearance of pisiform and sesamoid observed on serial hand and wrist roentgenograms in 50 males and 32 females.

| FACIAL DIMENSION | | PISIFORM | | SESAMOID | |
|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| (n-s) | | | | | |
| Magnitude | M | -.03 | .00 | -.04 | -.11 |
| | F | .16 | .08 | .04 | -.34 |
| | M + F | .05 | .03 | -.01 | -.21 |
| Chron.Age | M | .11 | -.01 | .56** | .19 |
| | F | .41 | .00 | .71** | .48* |
| | M + F | .25 | .00 | .63** | .32* |
| Skelet.Age | M | .18 | .22 | .19 | .34 |
| | F | -.16 | .24 | .12 | .34 |
| | M + F | .02 | .23 | .16 | .34* |
| (pm-sp) | | | | | |
| Magnitude | M | -.58* | -.25 | -.26 | .08 |
| | F | -.39 | -.52* | .18 | .23 |
| | M + F | -.49** | -.40* | -.03 | .16 |
| Chron.Age | M | .61** | .45 | .40 | .18 |
| | F | .42 | -.17 | .77** | .38 |
| | M + F | .52** | .15 | .63** | .29 |
| Skelet.Age | M | .44 | .57* | .08 | .30 |
| | F | .02 | .02 | .42 | .28 |
| | M + F | .23 | .31 | .27 | .29 |

*Coefficients significant at $p < .05$

**Coefficients significant at $p < .01$

++Difference between males and females significant at $p < .01$

TABLE 21(b)

| FACIAL DIMENSION | | PISIFORM | | SESAMOID | |
|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| (pg-ar) | | | | | |
| Magnitude | M | -.17 | -.06 | -.27 | -.09 |
| | F | -.31 | -.27 | -.20 | -.14 |
| | M + F | -.22 | -.13 | -.25 | -.11 |
| Chron.Age | M | .32 | .19 | .52** | .34 |
| | F | .57* | .06 | .60* | .34 |
| | M + F | .42** | .14 | .55** | .34* |
| Skelet.Age | M | .24 | .41 | .18 | .58** |
| | F | .41 | .29 | .11 | .03 |
| | M + F | .31 | .36* | .15 | .38* |
| (pg-go) | | | | | |
| Magnitude | M | -.01 | -.09 | -.22 | -.34 |
| | F | -.55* | -.49* | .07 | .23 |
| | M + F | -.28 | -.28 | -.11 | -.13 |
| Chron.Age | M | .42 | .34 | .65** | .39* |
| | F | .10 | -.05 | .62** | .33 |
| | M + F | .28 | .16 | .64** | .37* |
| Skelet.Age | M | .23 | .48* | .34 | .78** |
| | F | -.39 | .10 | -.21 | -.07 ++ |
| | M + F | -.08 | .31 | .12 | .52** |
| (ar-go) | | | | | |
| Magnitude | M | -.05 | -.14 | -.09 | .01 |
| | F | -.54* | -.11 | -.43 | -.30 |
| | M + F | -.27 | -.13 | -.23 | -.11 |
| Chron.Age | M | -.15 | -.42 | -.01 | -.28 |
| | F | .62** ++ | -.03 | .56* | .14 |
| | M + F | .20 | .27 | .23 | -.12 |
| Skelet.Age | M | -.45 | -.48 ++ | -.32 | -.10 |
| | F | .10 | .38 | -.33 | -.45 |
| | M + F | -.20 | -.08 | -.32 | -.28 |

* Coefficients significant at p < .05

** Coefficients significant at p < .01

++ Difference between males and females significant at p < .01

TABLE 21(c)

| FACIAL DIMENSION | | PISIFORM | | SESAMOID | |
|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| (n-gn) | | | | | |
| Magnitude | M | .18 | .13 | -.05 | -.22 |
| | F | -.22 | .37 | -.63* | -.62* |
| | M + F | .07 | .20 | -.25 | -.36* |
| Chron.Age | M | .44* | .12 | .68** | .33 |
| | F | .76** | .08 | .83** | .41 |
| | M + F | .55** | .11 | .73** | .36* |
| Skelet.Age | M | .07 | .10 | .19 | .30 |
| | F | .34 | .04 | .39 | .28 |
| | M + F | .15 | .08 | .26 | .29 |
| (n-sp) | | | | | |
| Magnitude | M | -.13 | -.19 | -.02 | -.12 |
| | F | -.02 | .15 | .13 | .36 |
| | M + F | -.09 | -.08 | .03 | .04 |
| Chron.Age | M | .18 | -.23 ++ | .33 | -.05 |
| | F | .51 | .60* | .33 | .43 |
| | M + F | .29 | .05 | .33* | .11 |
| Skelet.Age | M | -.04 | -.24 ++ | .17 | .03 |
| | F | .25 | .71* | -.15 | .09 |
| | M + F | .04 | .06 | .08 | .05 |
| (id-gn) | | | | | |
| Magnitude | M | -.03 | .18 | -.05 | .26 |
| | F | -.15 | -.06 | -.14 | -.18 |
| | M + F | -.07 | .11 | -.08 | .14 |
| Chron.Age | M | .48* | .29 | .66** | .56** |
| | F | .50 | -.15 | .86** | .57 |
| | M + F | .49** | .15 | .73** | .57** |
| Skelet.Age | M | .37 | .44 | .35 | .75** |
| | F | -.18 | -.24 | .13 | .46 |
| | M + F | .20 | .24 | .29 | .68** |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 21(d)

| FACIAL DIMENSION | | PISIFORM | | SESAMOID | |
|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| (pr-id) | | | | | |
| Magnitude | M | -.05 | -.24 | .14 | -.17 |
| | F | -.49 | -.35 | -.10 | -.05 |
| | M + F | -.18 | -.27 | .07 | -.14 |
| Chron.Age | M | .58** | .27 | .45* | .29 |
| | F | .88** | .68* | .24 | -.05 |
| | M + F | .69** | .40* | .39* | .20 |
| Skelet.Age | M | .59* | .61* | .15 | .33 |
| | F | .48 | .78* | -.39 | -.35 |
| | M + F | .56** | .67** | -.06 | .08 |
| (pm-s) | | | | | |
| Magnitude | M | -.03 | -.10 | -.01 | -.16 |
| | F | -.44 | -.49* | .23 | .26 |
| | M + F | -.22 | -.29 | .09 | .01 |
| Chron.Age | M | -.05 | -.36 | .53** | .25 |
| | F | .09 | -.32 | .74** | .31 |
| | M + F | .01 | -.34* | .63** | .28 |
| Skelet.Age | M | -.13 | -.29 | .12 | .22 |
| | F | -.56* | -.07 | -.24 | -.31 |
| | M + F | -.36* | -.19 | -.04 | -.01 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 22(a). Correlations between timing and magnitude of peak velocity in facial dimensions and time of attaining different stages of maturation in the sesamoid observed on serial hand and wrist roentgenograms in 50 males and 32 females.

| FACIAL DIMENSION | | SESAMOID-STAGE 1 | | SESAMOID-STAGE 2 | | SESAMOID-STAGE 3 | |
|---|---|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| n-s | | | | | | | |
| Magnitude | M | Insufficient paired observations | | .44 | .28 | .20 | .38 |
| | F | -.59 | -.60 | .52 | .05 | .10 | -.03 |
| | M + F | Insufficient paired observations | | .49* | .17 | .16 | .21 |
| Chron.Age | M | Insufficient paired observations | | .85* | .28 | .56* | .32 |
| | F | .74* | .44 | .56 | -.01 | .66** | .38 |
| | M + F | Insufficient paired observations | | .74** | .14 | .61** | .35 |
| Skelet.Age | M | Insufficient paired observations | | .65 | .85** | .04 | .23 |
| | F | .25 | .20 | -.11 | .12 | -.10 | .08 |
| | M + F | Insufficient paired observations | | .26 | .54* | -.03 | .15 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 22(b)

| FACIAL DIMENSION | | SESAMOID-STAGE 1 | | SESAMOID-STAGE 2 | | SESAMOID-STAGE 3 | |
|---|---|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| pm-sp | | | | | | | |
| Magnitude | M | Insufficient paired observations | | .08 | -.55 | -.29 | .16 |
| | F | .21 | .57 | .44 | .45 | .09 | -.09 |
| | M + F | Insufficient paired observations | | .29 | -.02 | -.11 | .04 |
| Chron.Age | M | Insufficient paired observations | | .69 | .36 | .50 | .30 |
| | F | .81* | .28 | .58 | -.02 | .90** | .64* |
| | M + F | Insufficient paired observations | | .63** | .16 | .75** | .48* |
| Skelet.Age | M | Insufficient paired observations | | .19 | .24 | .20 | .48 |
| | F | .35 | .23 | .22 | -.14 | .60 | .58 |
| | M + F | Insufficient paired observations | | .21 | .01 | .41 | .53* |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 22(c)

| FACIAL DIMENSION | | SESAMOID-STAGE 1 | | SESAMOID-STAGE 2 | | SESAMOID-STAGE 3 | |
|---|---|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| <u>pg-ar</u> | | | | | | | |
| Magnitude | M | Insufficient paired observations | | .09 | .05 | -.35 | -.14 |
| | F | -.42 | -.21 | -.34 | -.30 | -.28 | -.23 |
| | M + F | Insufficient paired observations | | -.10 | -.11 | -.33 | -.17 |
| Chron.Age | M | Insufficient paired observations | | .66* | .08 | .73** | .71** |
| | F | .20 | .19 | .56 | .13 | .85** | .64* |
| | M + F | Insufficient paired observations | | .62** | .10 | .78** | .68** |
| Skelet.Age | M | Insufficient paired observations | | .23 | .32 | .29 | .73** |
| | F | -.12 | -.04 | .02 | .00 | .56 | .58 |
| | M + F | Insufficient paired observations | | .12 | .15 | .41* | .68** |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 22(d)

| FACIAL DIMENSION | | SESAMOID-STAGE 1 | | SESAMOID-STAGE 2 | | SESAMOID-STAGE 3 | |
|---|---|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| pg-go | | | | | | | |
| Magnitude | M | Insufficient paired observations | | -.36 | -.25 | -.33 | -.45* |
| | F | -.72 | -.92* | .23 | .47 | .04 | .20 |
| | M + F | Insufficient paired observations | | -.11 | .08 | -.18 | -.19 |
| Chron.Age | M | Insufficient paired observations | | .82** | .34 | .76** | .48** |
| | F | .33 | -.13 | .53 | .18 | .75** | .66** |
| | M + F | Insufficient paired observations | | .72** | .27 | .75** | .56** |
| Skelet.Age | M | Insufficient paired observations | | .51 | .67* | .30 | .68** |
| | F | -.64 | -.75 | -.19 | .13 | -.06 | .20 |
| | M + F | Insufficient paired observations | | .18 | .44 | .14 | .49** |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 22(e)

| FACIAL DIMENSION | | SESAMOID-STAGE 1 | | SESAMOID-STAGE 2 | | SESAMOID-STAGE 3 | |
|---|---|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| ar-go | | | | | | | |
| Magnitude | M | Insufficient paired observations | | .12 | -.07 | -.16 | -.01 |
| | F | -.40 | -.27 | -.61 | .01 | -.33 | -.07 |
| | M + F | Insufficient paired observations | | -.24 | -.04 | -.23 | -.03 |
| Chron.Age | M | Insufficient paired observations | | .69* | .02 | -.03 | -.15 |
| | F | .53 | .15 | .59 | -.01 | .57 | .14 |
| | M + F | Insufficient paired observations | | .65** | .01 | .24 | -.03 |
| Skelet.Age | M | Insufficient paired observations | | .13 | .15 | -.43 | -.07 |
| | F | -.09 | -.18 | -.24 | -.14 | -.57 | -.51 |
| | M + F | Insufficient paired observations | | -.07 | -.01 | -.51* | -.32 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 22(f)

| FACIAL DIMENSION | | SESAMOID-STAGE 1 | | SESAMOID-STAGE 2 | | SESAMOID-STAGE 3 | |
|---|---|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| n-gn | | | | | | | |
| Magnitude | M | Insufficient paired observations | | .28 | .14 | .06 | .06 |
| | F | .75 | .75 | -.21 | .43 | -.62 | -.61 |
| | M + F | Insufficient paired observations | | .13 | .23 | -.18 | -.17 |
| Chron.Age | M | Insufficient paired observations | | .73** | .14 | .74** | .39 |
| | F | -.51 | -.51 | .68 | -.30 | .92** | .74* |
| | M + F | Insufficient paired observations | | .71 | .00 | .82** | .52** |
| Skelet.Age | M | Insufficient paired observations | | .41 | .39 | .21 | .34 |
| | F | -.53 | -.53 | -.07 | -.19 | .54 | .59 |
| | M + F | Insufficient paired observations | | .23 | .17 | .33 | .43* |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 22(g)

| FACIAL DIMENSION | | SESAMOID-STAGE 1 | | SESAMOID-STAGE 2 | | SESAMOID-STAGE 3 | |
|---|---|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| n-sp | | | | | | | |
| Magnitude | M | Insufficient paired observations | | .23 | .03 | -.22 | -.07 |
| | F | .19 | .15 | .38 | .24 | -.13 | -.13 |
| | M + F | Insufficient paired observations | | .30 | .12 | -.20 | -.09 |
| Chron.Age | M | Insufficient paired observations | | .55 | -.04 | .41 | .08 |
| | F | -.15 | -.10 | -.02 | -.26 | .10 | .04 |
| | M + F | Insufficient paired observations | | .34 | -.13 | .32 | .07 |
| Skelet.Age | M | Insufficient paired observations | | .34 | .11 | .26 | .19 |
| | F | -.42 | -.20 | -.40 | -.41 | -.47 | -.44 |
| | M + F | Insufficient paired observations | | .07 | -.22 | .06 | .01 |

* Coefficients significant at p < .05

** Coefficients significant at p < .01

++ Difference between males and females significant at p < .01

TABLE 22(h)

| FACIAL DIMENSION | | SESAMOID-STAGE 1 | | SESAMOID-STAGE 2 | | SESAMOID-STAGE 3 | |
|---|---|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| id-gn | | | | | | | |
| Magnitude | M | Insufficient paired observations | | .04 | .23 | -.14 | .21 |
| | F | .35 | .25 | -.49 | .19 | .09 | .26 |
| | M + F | Insufficient paired observations | | .17 | .22 | -.07 | .22 |
| Chron.Age | M | Insufficient paired observations | | .90** | .42 | .69** | .59* |
| | F | .79 | .52 | .75 | -.38 | .79* | .40 |
| | M + F | Insufficient paired observations | | .86** | .14 | .72** | .54** |
| Skelet.Age | M | Insufficient paired observations | | .59 | .65* | .34 | .68* |
| | F | .03 | -.08 | -.28 | .25 | .08 | .27 |
| | M + F | Insufficient paired observations | | .37 | .55* | .25 | .55** |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 22(i)

| FACIAL DIMENSION | | SESAMOID-STAGE 1 | | SESAMOID-STAGE 2 | | SESAMOID-STAGE 3 | |
|---|---|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| <u>pr-id</u> | | | | | | | |
| Magnitude | M | Insufficient paired observations | | .37 | -.01 | .25 | .02 |
| | F | .63 | .63 | .33 | .80 | -.01 | .20 |
| | M + F | Insufficient paired observations | | .36 | .27 | .18 | .07 |
| Chron.Age | M | Insufficient paired observations | | .43 | .46++ | .64* | .27 |
| | F | -.51 | -.51 | -.28 | -.88* | .60 | .60 |
| | M + F | Insufficient paired observations | | .26 | .02 | .63** | .37 |
| Skelet.Age | M | Insufficient paired observations | | -.11 | .46++ | .43 | .25 |
| | F | -.53 | -.53 | -.86 | -.95* | -.26 | .14 |
| | M + F | Insufficient paired observations | | .52 | -.41 | .22 | .21 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 22(j)

| FACIAL DIMENSION | | SESAMOID-STAGE 1 | | SESAMOID-STAGE 2 | | SESAMOID-STAGE 3 | |
|---|---|---|---|---|---|---|---|
| | | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age | Chron.Age | Skelet.Age |
| pm-s | | | | | | | |
| Magnitude | M | Insufficient paired observations | | -.18 | -.61++ | .30 | .41 |
| | F | -.11 | -.63 | .14 | .48 | .20 | .23 |
| | M + F | Insufficient paired observations | | -.04 | -.17 | .25 | .33 |
| Chron.Age | M | Insufficient paired observations | | .51 | .02 | .85** | .63** |
| | F | .74 | .22 | .72* | .18 | .66** | .25 |
| | M + F | Insufficient paired observations | | .61** | .09 | .78** | .48** |
| Skelet.Age | M | Insufficient paired observations | | .07 | -.15 | .37++ | .74**++ |
| | F | -.01 | -.51 | -.19 | -.05 | -.43 | -.46 |
| | M + F | Insufficient paired observations | | -.05 | -.10 | -.05 | .19 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 23. Correlations between time of appearance (chronological age) of ossification events observed on serial hand and wrist roentgenograms in 50 males and 32 females.

| VARIABLE | | HAMATE | | SESAMOID | SESAMOID SIZE | | |
|---|---|---|---|---|---|---|---|
| | | Stage 1 | Stage 2 | | Stage 1 | Stage 2 | Stage 3 |
| PISIFORM | M | .74** | .66** | .67** | .90* | .61* | .63** |
| | F | .87** | .45* | .54** | .56 | .41 | .67** |
| | M + F | .80** | .59** | .62** | .69** | .53** | .64** |
| HAMATE | | | | | | | |
| Stage 1 | M | | .67** | .56** | .83 | .43 | .57* |
| | F | | .83** | .71** | .49 | -.05 | .48** |
| | M + F | | .74** | .62** | .61 | .45 | .67** |
| Stage 2 | M | | | .88** | .99 | .81** | .78** |
| | F | | | .87** | .95** | .86** | .68** |
| | M + F | | | .87** | .00 | .83** | .75** |
| SESAMOID | M | | | | 1.00 | 1.00 | .89** |
| | F | | | | 1.00 | .89** | .88** |
| | M + F | | | | .00 | .00 | .89** |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 24. Correlations between time of appearance (skeletal age) of ossification events observed on serial hand and wrist roentgenograms in 50 males and 32 females.

| VARIABLE | | HAMATE | | SESAMOID | SESAMOID SIZE | | |
|---|---|---|---|---|---|---|---|
| | | Stage 1 | Stage 2 | | Stage 1 | Stage 2 | Stage 3 |
| <u>PISIFORM</u> | M | .52** | .29 | .42* ++ | .17 | .35 | .34 |
| | F | .46 | .01 | -.16 | .26 | -.24 | -.03 |
| | M + F | .50** | .19 | .21 | .23 | .10 | .18 |
| <u>HAMATE</u> | | | | | | | |
| Stage 1 | M | | .77** | .38 | .25 | .27 | .50* |
| | F | | .35 | -.03 | -.29 | -.40 | -.42 |
| | M + F | | .64** | .23 | -.16 | -.07 | .47* |
| Stage 2 | M | | | .59** | -.25 | .31 | .46* |
| | F | | | .47* | .74* | .53 | -.21 |
| | M + F | | | .55** | .00 | .40* | .22 |
| <u>SESAMOID</u> | M | | | | 1.00 | 1.00 | .59** |
| | F | | | | 1.00 | .59* | .43 |
| | M + F | | | | .00 | .00 | .53** |

* Coefficients significant at p < .05

** Coefficients significant at p < .01

++ Difference between males and females significant at p < .01

TABLE 25. Correlations between the magnitude of peak velocity in facial dimensions in 50 males and 32 females.

| VARIABLE | | pm-sp | pg-ar | pg-go | ar-go | n-gn | n-sp | id-gn | pr-id | pm-s |
|---|---|---|---|---|---|---|---|---|---|---|
| n-s | M | .10 | -.11 | -.35 | -.24 | .68** | -.02 | .02 | .10 | .55* |
| | F | .18 | -.10 | .22 | -.07 | .29 | .15 | -.42 | .33 | .16 |
| | M + F | .15 | -.11 | -.10 | -.17 | .56** | .05 | -.15 | .18 | .38* |
| pm-sp | M | | -.27 | -.21 | .17 | -.01 | .30++ | .19 | .00 | -.09 |
| | F | | .51 | .45 | .15 | .33 | .03 | .03 | .49 | .41 |
| | M + F | | .41* | .12 | .16 | .14 | .17 | .12 | .22 | .19 |
| pg-ar | M | | | .39 | .85** | .30 | .30 | .20 | .32 | -.07 |
| | F | | | .37 | .58* | .03 | -.53 | .23 | -.12 | .25 |
| | M + F | | | .39* | .76** | .21 | .00 | .21 | .16 | .06 |
| pg-go | M | | | | .36 | .19++ | -.16 | .13 | .10 | -.19 |
| | F | | | | .08 | -.58* | .12 | -.03 | -.06 | .36 |
| | M + F | | | | .25 | -.09 | -.07 | .07 | .05 | .07 |
| ar-go | M | | | | | .10 | .22 | .22 | .49 | .05 |
| | F | | | | | .21 | -.59 | -.04 | .13 | .23 |
| | M + F | | | | | .14 | -.13 | .13 | .37 | .13 |
| n-gn | M | | | | | | .57* | .38 | .16 | .33 |
| | F | | | | | | -.13 | .38 | .56 | .28 |
| | M + F | | | | | | .40* | .38* | .32 | .31 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 25 (continued)

| VARIABLE | | pm-sp | pg-ar | pg-go | ar-go | n-gn | n-sp | id-gn | pr-id | pm-s |
|---|---|---|---|---|---|---|---|---|---|---|
| n-sp | M | | | | | | | .38 | .21 | .11 |
| | F | | | | | | | .15 | .14 | -.01 |
| | M + F | | | | | | | .32 | .20 | .06 |
| id-gn | M | | | | | | | | .22 | .31 |
| | F | | | | | | | | .28 | .14 |
| | M + F | | | | | | | | .24 | .25 |
| pr-id | M | | | | | | | | | .33 |
| | F | | | | | | | | | .26 |
| | M + F | | | | | | | | | .31 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 26. Correlations between time (chronological age) of peak velocity in facial dimensions in 50 males and 32 females.

| VARIABLE | | pm-sp | pg-ar | pg-go | ar-go | n-gn | n-sp | id-gn | pr-id | pm-s |
|---|---|---|---|---|---|---|---|---|---|---|
| n-s | M | .51 | .87**++ | .90**++ | .56** | .84** | .56** | .88** | .44 | .85** |
| | F | .68 | .52* | .55* | .69* | .39** | .60 | .49* | .76 | .76** |
| | M + F | .61** | .78** | .80** | .53** | .79** | .50** | .81** | .45* | .81** |
| pm-sp | M | | .39 | .59* | -.08++ | .48++ | .76** | .45 | .72** | .31 |
| | F | | .80** | .58** | .84** | .90** | .63* | .73* | .75* | .68** |
| | M + F | | .66** | .59** | .54** | .74** | .70** | .58** | .73** | .53** |
| pg-ar | M | | | .89** | .55** | .74** | .46 | .89** | .39 | .82** |
| | F | | | .72** | .71** | .90** | .57 | .26++ | .53 | .47 |
| | M + F | | | .84** | .62** | .82** | .50** | .76** | .45* | .72** |
| pg-go | M | | | | .39 | .77** | .48* | .88** | .50* | .80** |
| | F | | | | .61* | .64* | .32 | .13++ | .28 | .62** |
| | M + F | | | | .49** | .73** | .43* | .73** | .44* | .73** |
| ar-go | M | | | | | .41 | .72** | .25 | .11 | .54* |
| | F | | | | | .61* | .51 | .34 | .71* | .60** |
| | M + F | | | | | .49** | .65** | .28 | .38 | .57** |
| n-gn | M | | | | | | .55* | .79** | .66** | .80** |
| | F | | | | | | .66 | .65* | .72* | .73** |
| | M + F | | | | | | .58** | .75** | .68** | .78** |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 26 (continued)

| VARIABLE | | pm-sp | pg-ar | pg-go | ar-go | n-gn | n-sp | id-gn | pr-id | pm-s |
|---|---|---|---|---|---|---|---|---|---|---|
| n-sp | M | | | | | | | .34 | .67** | .56* |
| | F | | | | | | | -.08 | .51 | .40 |
| | M + F | | | | | | | .24 | .64** | .51** |
| id-gn | M | | | | | | | | .53 | .79** |
| | F | | | | | | | | .48 | .66** |
| | M + F | | | | | | | | .51* | .75** |
| pr-id | M | | | | | | | | | .45 |
| | F | | | | | | | | | .48 |
| | M + F | | | | | | | | | .47* |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 27. Correlations between time (skeletal age) of peak velocity in facial dimensions in 50 males and 32 females.

| VARIABLE | | pm-sp | pg-ar | pg-go | ar-go | n-gn | n-sp | id-gn | pr-id | pm-s |
|---|---|---|---|---|---|---|---|---|---|---|
| n-s | M | .61* | .74** | .73** | .70** | .61** | .65** | .77** | .38 | .53* |
| | F | .62** | .52 | .74** | .39 | .45 | .62* | .82** | .47 | .75** |
| | M + F | .62** | .66** | .74** | .55** | .55** | .64** | .79** | .42 | .66** |
| pm-sp | M | | .58 | .57* | -.05 | .19 | .54 | .70* | .62* | .44 |
| | F | | .52* | .59* | .55* | .59* | .74* | .36 | .49 | .45 |
| | M + F | | .54** | .58** | .36 | .40* | .64** | .58** | .56** | .44* |
| pg-ar | M | | | .95** | .55* | .48* | .41 | .87** | .39 | .74** |
| | F | | | .61*++ | .78** | .82** | .78* | .22++ | .35 | .06++ |
| | M + F | | | .86** | .68** | .66** | .58** | .69** | .37 | .51** |
| pg-go | M | | | | .56* | .55* | .52* | .88** | .46 | .76** |
| | F | | | | .48 | .43 | .36 | .06++ | .11 | .71** |
| | M + F | | | | .52** | .51** | .47* | .72** | .33 | .74** |
| ar-go | M | | | | | .82** | .77** | .43 | -.05 | .64* |
| | F | | | | | .54 | .91** | .30 | .41 | .42 |
| | M + F | | | | | .73** | .84** | .37 | .17 | .53** |
| n-gn | M | | | | | | .59* | .60* | .44 | .56* |
| | F | | | | | | .68 | .42 | .17 | .26 |
| | M + F | | | | | | .62** | .53** | .34 | .45* |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

++ Difference between males and females significant at $p < .01$

TABLE 27 (continued)

| VARIABLE | | pm-sp | pg-ar | pg-go | ar-go | n-gn | n-sp | id-gn | pr-id | pm-s |
|---|---|---|---|---|---|---|---|---|---|---|
| n-sp | M | | | | | | | .39 | .33 | .79** |
| | F | | | | | | | .17 | .76 | .52 |
| | M + F | | | | | | | .34 | .43 | .71** |
| id-gn | M | | | | | | | | .43 | .61 |
| | F | | | | | | | | -.08 | .18 |
| | M + F | | | | | | | | .24 | .44 |
| pr-id | M | | | | | | | | | .23 |
| | F | | | | | | | | | .10 |
| | M + F | | | | | | | | | .18 |

* Coefficients significant at $p < .05$

** Coefficients significant at $p < .01$

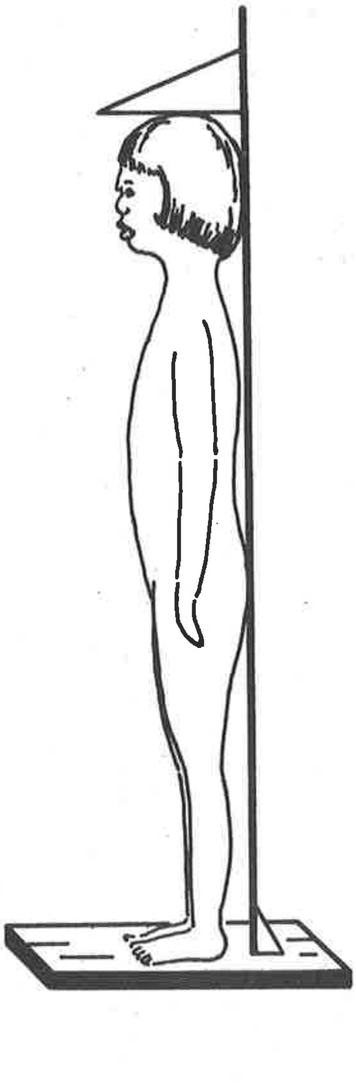
++ Difference between males and females significant at $p < .01$

# DISCUSSION

To simplify the discussion, the correlation analysis will be discussed under the following headings:

* ossification events and stature
* stature and facial growth
* ossification events and facial growth
* ossification events
* facial growth

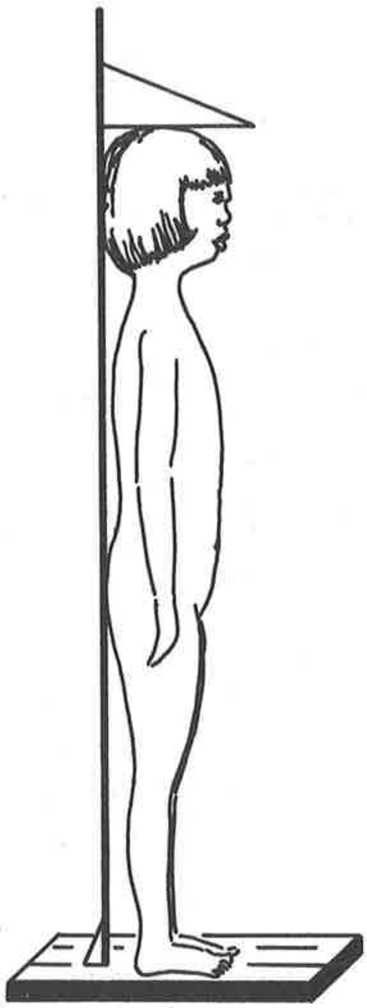
Diagrams identify the matrix segment being described.

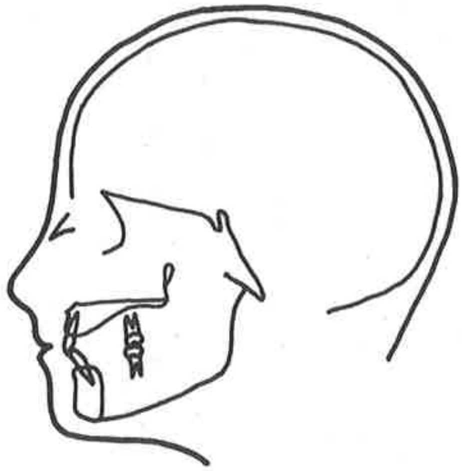


# OSSIFICATION EVENTS AND STATURE

Refer TABLE 18

In both males and females associations between the chronological ages-at-appearance of the sesamoid and peak velocity in stature were high ($r = 0.84$ in males and $r = 0.85$ in females). These values were slightly in excess to those values given by BJÖRK and HELM ('67), where $r = 0.75$ in males and $r = 0.57$ in females. Moreover, a high correlation ($r = 0.92$) existed between the chronological age at peak velocity in stature and sesamoid-stage 2 in males. Chronologic age at peak stature was moderately correlated with chronological age-at-appearance of the pisiform ($r = 0.62$) and ossification of the hook of the hamate-stage 2 ($r = 0.78$).





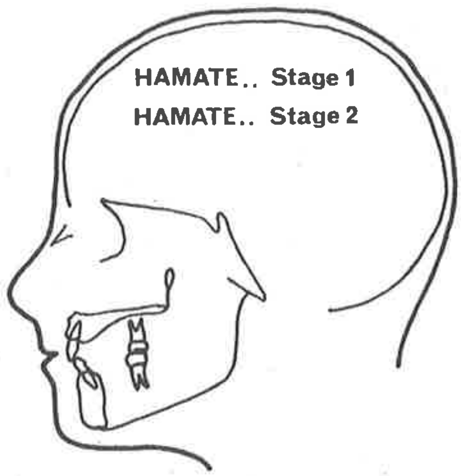
## STATURE AND FACIAL GROWTH

Refer TABLE 19(a), (b), (c), (d) and (e)

High correlations were found between the chronological ages at peak velocity in stature and peak velocity in n-s (r = 0.83), pg-go (r = 0.83), n-gn (r = 0.84) and id-gn (r = 0.86). In males, chronological age at peak velocity in mandibular face height showed an extremely high correlation (r = 0.90) {Table 19(d)} with chronological age at peak velocity in stature. The correlations between chronological ages at peak velocity in stature and various facial dimensions differed significantly from zero for all variables except n-sp {Table 19(d)}.

OSSIFICATION EVENTS AND FACIAL GROWTH

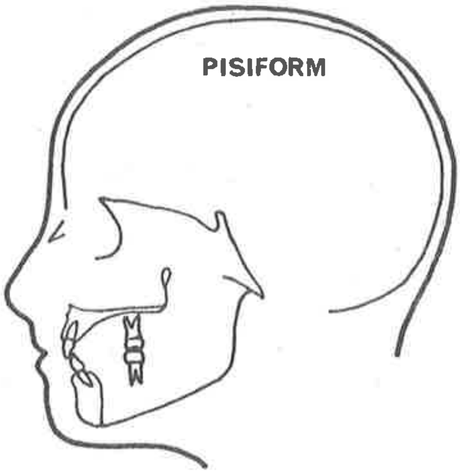
(Refer Tables 20, 21 and 22)




Refer Tables 20(a), (b), (c) and (d)

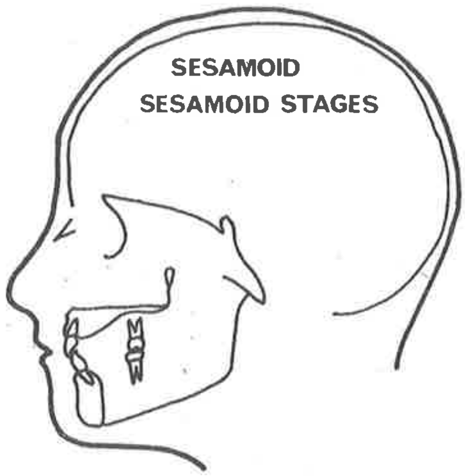
Chronological age at peak velocity for pm-sp, pg-ar and pr-id showed a somewhat stronger association with chronological age-at-appearance of hamate-stage 1 than with hamate-stage 2. These correlations were moderate in all instances except pr-id, which revealed a high correlation (r = 0.92) in females (Table 20c). Chronological age-at-appearance of hamate-stage 2 was moderately correlated with chronological age at peak velocity for the variables, n-s (r = 0.44), pm-sp (r = 0.60), pg-ar (r = 0.44), pg-go (r = 0.57), n-gn (r = 0.65), id-gn (r = 0.69) and pm-s (r = 0.68). It was not significantly correlated with variables ar-go (r = 0.13) (Table 20b), and pr-id (r = 0.34) (Table 20c).

Refer Tables 21(a), (b), (c) and (d)




The chronological age-at-appearance of the pisiform was only moderately correlated with chronological age at peak velocity in several facial dimensions. The remainder of the correlations were non significant. However, a significant sex difference was shown for the association between chronological ages-at-appearance of the pisiform and at peak velocity in ar-go (in males, r = 0.15 and in females r = 0.62 (Table 21b).

Refer Tables 21(a - d) and 22(a - j)

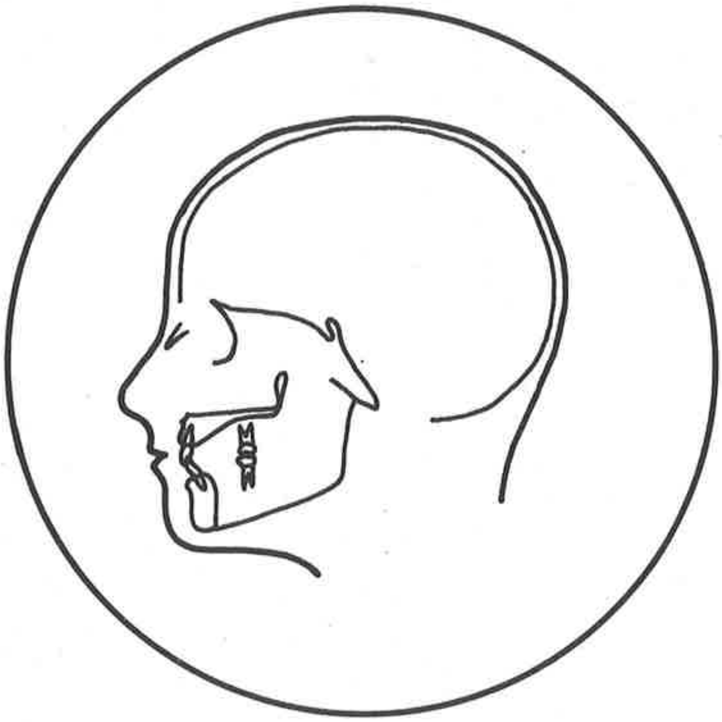



The chronological age-at-appearance of the sesamoid was only moderately correlated with chronological age at peak velocity in most facial dimensions. The correlations between the age-at-appearance of sesamoid and peak velocities of the variables ar-go (r = 0.23), n-sp (r = 0.33) and pr-id (r = 0.39) were the exceptions. However, the time of peak velocity of the variable ar-go was moderately correlated (r = 0.65) with age-at-appearance of sesamoid-stage 2 (Table 22c). The associations between chronological ages at peak velocity in facial dimensions and the sesamoid were somewhat stronger as the sesamoid increased in size. In fact, chronological ages-at-appearances of sesamoid-stage 2 and sesamoid-stage 3 were highly correlated with time of peak velocity of variables id-gn (r = 0.86) (Table 22h) and n-gn (r = 0.82) (Table 22f) respectively.

# OSSIFICATION EVENTS

Refer TABLES 23 and 24

Chronological ages-at-appearance of the pisiform and hamate-stage 1 were highly correlated ($r = 0.80$) (Table 23). A similar association was evident between hamate-stage 2 and sesamoid-stage 2 ($r = 0.83$) (Table 23). Most other variables considered in this section were only moderately correlated.



# FACIAL GROWTH

Refer TABLES 25, 26 and 27

Coefficients of correlation indicated a general low relationship between the magnitude of peak velocity in most facial dimensions. Table 25 shows four coefficients were moderate and 38 did not differ significantly from zero at the $p = 0.05$ level. The significant correlations might be expected topographically, as reference points were shared. Magnitude of peak velocity of variable pm-sp was moderately correlated ($r = 0.41$) with the variable pg-ar but revealed no marked associations with other facial variables. The apparent independence of facial components is not surprising because the facial skeleton is made up of a number of bones all of which may be subject to a variety of influences during growth.

Correlations between the chronological age at peak velocity in the facial dimensions were generally strong. Table 26 shows five coefficients were high, 37 were moderate and three did not differ significantly from zero at the 0.1 level.

## SUMMARY


1. In both males and females associations between the chronological ages-at-appearance of the sesamoid and peak velocity in stature were high .
2. Generally, moderate to high coefficients of correlation were found between the chronological ages at peak velocity in stature and peak velocity in most facial dimensions. However, in males, chronological age at peak velocity in mandibular face height showed an extremely high correlation with chronological age at peak velocity in stature.
3. Of the selected ossification events only the sesamoid was moderately correlated with chronological age at peak velocity in most facial dimensions. The associations between chronological ages at peak velocity in facial dimensions and the sesamoid were somewhat stronger as the sesamoid increased in size.
4. The chronological ages-at-appearance of the pisiform and hamate-stage 1 were highly correlated. A similar association was evident between hamate-stage 2 and sesamoid-stage 2.
5. Coefficients of correlation revealed a general low relationship between the magnitude of peak velocity in most facial dimensions. However, a generally stronger relationship existed between the chronological age at peak velocity in the facial dimensions.

CHAPTER VII

# RELATIONS IN TIME BETWEEN GROWTH EVENTS

The intervals between the time of initial appearance of ossification events observed on hand and wrist roentgenograms and the time of maximum growth velocity in stature and various facial dimensions were determined. In each paired comparison the interval was recorded in decimal years as the difference between the mid-points of the years in which the two events occurred.

## METHODS

For each subject the time of initial appearance of the selected carpal ossification centres and the calculated time of peak growth velocity in stature and facial dimensions were entered on punched cards. Time was recorded as chronological age as previously discussed. A computer was used to determine the time intervals between all paired events. One hundred and fifty three such comparisons were made; they are listed in Appendix C.

The time intervals were calculated for males and females separately. Descriptive statistics, in the form of the mean, error of the mean, standard deviation and range, were computed in each instance. For convenience, time intervals between events were classified on a scale ranging from -3 to +3 as follows:

Classification of timing differences

| Category | Years | Years |
|---|---|---|
| (-3) | | $T \leq -2.5$ |
| (-2) | $-2.5 <$ | $T \leq -1.5$ |
| (-1) | $-1.5 <$ | $T \leq -0.5$ |
| (0) | $-0.5 <$ | $T \leq 0.5$ |
| (1) | $0.5 <$ | $T \leq 1.5$ |
| (2) | $1.5 <$ | $T \leq 2.5$ |
| (3) | $2.5 <$ | $T$ |

Where T = time difference in decimal years between events

For example, if the interval between the timing of two events fell between -0.5 and 0.5 years, the events were regarded as occurring simultaneously and the interval was categorized as 0.

A statistical sign test (DIXON and MOOD, '46) was used to determine the significance of the difference between the number of subjects with positive and negative time intervals between the occurrence of two events, that is the significance of differences between the number of subjects where one event followed or preceded the other.

## RESULTS

Tables 28 - 32 list 48 time differences between variables for males and females separately. Significant differences between the timing of two events, as determined by the sign test referred to above, are designated in the tables according to the probability levels of 5% (*) and 1% (**).

Table 33 lists all paired comparisons in which there were no significant differences between the number of subjects having one event either preceding or following the other. That is, in these comparisons the event can be taken to occur within the same year.

Tables 34 - 37 list the percentage of subjects in which one event occurs before or after the other, as well as the mean and standard deviation of timing intervals between the two events. Male and female differences in the time interval between the ossification events studied and peak velocity in stature as well as the percentage of subjects with ossification events appearing before peak velocity in stature are illustrated in Fig. 14 which was drawn from mean values for both sexes.

TABLE 28. Time intervals recorded in decimal years, based on chronological age, between peak velocity in stature and carpal ossification in 50 males and 32 females.

| Paired Events | Subject Number | | Classification of Time Interval -3 N (%) | -2 N (%) | -1 N (%) | 0 N (%) | 1 N (%) | 2 N (%) | 3 N (%) | Earliest Occurring Event |
|---|---|---|---|---|---|---|---|---|---|---|
| STATURE | | | | | | | | | | PISIFORM |
| PISIFORM | M | 24 | | | | 5(20.8) | 13(54.2) | 3(12.5) | 3(12.5) | ** |
| | F | 16 | | | | 1( 6.3) | 11(68.7) | 2(12.5) | 2(12.5) | ** |
| STATURE | | | | | | | | | | HAMATE-STAGE 1 |
| HAMATE-STAGE 1 | M | 16 | | | | 2(12.5) | 6(37.5) | 5(31.2) | 3(18.8) | ** |
| | F | 13 | | | 1( 7.7) | 2(15.4) | 7(53.8) | 1( 7.7) | 2(15.4) | * |
| STATURE | | | | | | | | | | HAMATE-STAGE 2 |
| HAMATE-STAGE 2 | M | 26 | | | 1( 3.9) | 17(65.4) | 7(26.9) | 1( 3.8) | | * |
| | F | 15 | | | | 9(60.0 | 5(33.3) | 1( 6.7) | | * |
| STATURE | | | | | | | | | | SESAMOID |
| SESAMOID | M | 30 | | | | 22(73.3) | 7(23.3) | 1( 3.3) | | * |
| | F | 17 | | | 1( 5.9) | 7(41.2) | 9(52.9) | | | * |

* Time difference between paired events significant at p < .05

** Time difference between paired events significant at p < .01

TABLE 29. Time intervals recorded in decimal years, based on chronological age, between initial ossification of the pisiform and peak velocity in facial dimensions in 50 males and 32 females.

| Paired Events | Subject Number | | Classification of Time Interval -3 N (%) | -2 N (%) | -1 N (%) | 0 N (%) | 1 N (%) | 2 N (%) | 3 N (%) | Earliest Occurring Events |
|---|---|---|---|---|---|---|---|---|---|---|
| PISIFORM/n-s | M | 23 | 5(21.7) | 2( 8.7) | 10(43.5) | 4(17.4) | | 2( 8.7) | | PISIFORM ** |
| | F | 19 | 2(10.5) | 7(36.8) | 5(26.3) | 4(21.0) | 1( 5.3) | | | * |
| PISIFORM/pm-sp | M | 17 | 1( 5.9) | 1( 5.9) | 9(52.9) | 4(23.5) | 1( 5.9) | 1( 5.9) | | PISIFORM * |
| | F | 18 | 2(11.1) | 5(27.8) | 5(27.8) | 4(22.2) | 2(11.1) | | | * |
| PISIFORM/pg-ar | M | 24 | 4(16.7) | 3(12.5) | 11(45.8) | 5(20.8) | 1( 4.2) | | | PISIFORM ** |
| | F | 15 | 2(13.3) | 6(40.0) | 4(26.7) | 3(20.0) | | | | ** |
| PISIFORM/pg-go | M | 22 | 5(22.7) | 3(13.6) | 10(45.5) | 4(18.2) | | | | PISIFORM ** |
| | F | 19 | 2(10.5) | 8(42.1) | 5(26.3) | 3(15.8) | | | 1( 5.3) | ** |
| PISIFORM/ar-go | M | 21 | 6(28.6) | 2( 9.5) | 8(38.1) | 4(19.0) | | | 1( 4.8) | PISIFORM ** |
| | F | 15 | 1( 6.7) | 7(46.6) | 5(33.3) | 1( 6.7) | 1( 6.7) | | | ** |
| PISIFORM/n-gn | M | 23 | 3(13.0) | 4(17.4) | 10(43.5) | 4(17.4) | 2( 8.7) | | | PISIFORM ** |
| | F | 11 | 2(18.2) | 6(54.5) | 2(18.2) | 1( 9.1) | | | | ** |

* Time difference between paired events significant at $p < .05$

** Time difference between paired events significant at $p < .01$

TABLE 29 (continued)

| Paired Events | Subject | Number | Classification of Time Interval -3 N (%) | -2 N (%) | -1 N (%) | 0 N (%) | 1 N (%) | 2 N (%) | 3 N (%) | Earliest Occurring Events |
|---|---|---|---|---|---|---|---|---|---|---|
| PISIFORM/n-sp | M | 23 | No significant difference in the timing of the two events | | | | | | | PISIFORM |
| | F | 12 | 3(25.0) | 1( 8.3) | 5(41.7) | 3(25.0) | | | | ** |
| PISIFORM/id-gn | M | 20 | 5(25.0) | 1( 5.0) | 10(50.0) | 3(15.0) | 1( 5.0) | | | PISIFORM ** |
| | F | 11 | 4(36.4) | 3(27.3) | 3(27.3) | 1( 9.0) | | | | ** |
| PISIFORM/pr-id | M | 19 | No significant difference in the timing of the two events | | | | | | | PISIFORM |
| | F | 9 | 3(33.3) | 5(55.6) | 1(11.1) | | | | | ** |
| PISIFORM/pm-s | M | 21 | No significant difference in the timing of the two events | | | | | | | PISIFORM |
| | F | 18 | 3(16.7) | 5(27.8) | 6(33.3) | 3(16.7) | | | 1( 5.5) | ** |

* Time difference between paired events significant at $p < .05$

** Time difference between paired events significant at $p < .01$

TABLE 30. Time intervals recorded in decimal years, based on chronological age, between ossification of the hook of the hamate-stage 1 and peak velocity in facial dimensions in 50 males and 32 females.

| Paired Events | Subject | Number | Classification of Time Interval -3 N (%) | -2 N (%) | -1 N (%) | 0 N (%) | 1 N (%) | 2 N (%) | 3 N (%) | Earliest Occurring Event |
|---|---|---|---|---|---|---|---|---|---|---|
| HAMATE-Stage 1 n-s | | | | | | | | | | HAMATE-STAGE 1 |
| | M | 15 | 4(26.7) | 4(26.7) | 4(26.7) | 1( 6.6) | 2(13.3) | | | * |
| | F | 13 | 2(15.4) | 4(30.8) | 4(30.8) | 1( 7.7) | 2(15.3) | | | * |
| HAMATE-Stage 1 pm-sp | | | | | | | | | | HAMATE-STAGE 1 |
| | M | 11 | 1( 9.1) | 1( 9.1) | 6(54.6) | 3(27.2) | | | | ** |
| | F | 13 | 1( 7.6) | 4(30.8) | 4(30.8) | 4(30.8) | | | | ** |
| HAMATE-Stage 1 pg-ar | | | | | | | | | | HAMATE-STAGE 1 |
| | M | 16 | 3(18.8) | 5(31.2) | 6(37.5) | 2(12.5) | | | | ** |
| | F | 11 | | 5(45.4) | 4(36.4) | 2(18.2) | | | | ** |
| HAMATE-Stage 1 pg-go | | | | | | | | | | HAMATE-STAGE 1 |
| | M | 16 | 4(25.0) | 6(37.5) | 4(25.0) | 2(12.5) | | | | ** |
| | F | 13 | 1( 7.7) | 5(38.5) | 6(46.1) | 1( 7.7) | | | | ** |
| HAMATE-Stage 1 ar-go | | | | | | | | | | HAMATE-STAGE 1 |
| | M | 12 | 4(33.3) | 4(33.3) | 4(33.3) | | | | | ** |
| | F | 10 | 1(10.0) | 4(40.0) | 3(30.0) | 1(10.0) | 1(10.0) | | | * |

* Time difference between paired events significant at $p < .05$

** Time difference between paired events significant at $p < .01$

TABLE 30 (continued)

| Paired Events | Subject | Number | -3 N (%) | -2 N (%) | -1 N (%) | 0 N (%) | 1 N (%) | 2 N (%) | 3 N (%) | Earliest Occurring Event |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Classification of Time Interval | | | | | | | |
| HAMATE-Stage 1 | | | | | | | | | | HAMATE-STAGE 1 |
| n-gn | M | 14 | 2(14.3) | 5(35.7) | 4(28.6) | 2(14.3) | 1( 7.1) | | | ** |
| | F | 9 | 1(11.1) | 4(44.4) | 3(33.3) | | 1(11.1) | | | * |
| HAMATE-Stage 1 | | | | | | | | | | HAMATE-STAGE 1 |
| n-sp | M | 17 | 3(17.6) | 3(17.6) | 5(29.4) | 4(23.5) | | 1( 5.9) | 1( 5.9) | * |
| | F | 10 | No significant difference in the timing of the two events | | | | | | | |
| HAMATE-Stage 1 | | | | | | | | | | HAMATE-STAGE 1 |
| id-gn | M | 12 | 5(41.6) | 3(25.0) | 2(16.7) | 2(16.7) | | | | ** |
| | F | 8 | No significant difference in the timing of the two events | | | | | | | |
| HAMATE-Stage 1 | | | | | | | | | | HAMATE-STAGE 1 |
| pr-id | M | 15 | No significant difference in the timing of the two events | | | | | | | |
| | F | 6 | 1(16.7) | 5(83.3) | | | | | | * |
| HAMATE-Stage 1 | | | | | | | | | | HAMATE-STAGE 1 |
| pm-s | M | 15 | 2(13.3) | 6(40.0) | 4(26.6) | 1( 6.7) | 1( 6.7) | | 1( 6.7) | * |
| | F | 12 | 3(25.0) | 4(33.3) | 3(25.0) | 1( 8.3) | 1( 8.3) | | | * |

* Time difference between paired events significant at $p < .05$

** Time difference between paired events significant at $p < .01$

TABLE 31(a). Time intervals recorded in decimal years, based on chronological age, between ossification of the hook of the hamate-stage 2 and sesamoid, and peak velocity in facial dimensions in 50 males and 32 females.

| Paired Event | Subject | Number | Classification of time Interval -3 N (%) | -2 N (%) | -1 N (%) | 0 N (%) | 1 N (%) | 2 N (%) | 3 N (%) | Earliest Occurring Event |
|---|---|---|---|---|---|---|---|---|---|---|
| HAMATE-Stage 2 n-s | | | | | | | | | | HAMATE-STAGE 2 |
| | M | 23 | 1( 4.3) | 1( 4.3) | 8(34.8) | 11(47.8) | 1( 4.3) | 1( 4.3) | | * |
| | F | 17 | 1( 5.9) | 2(11.7) | 6(35.3) | 7(41.2) | | 1( 5.9) | | * |
| HAMATE-Stage 2 pg-go | | | | | | | | | | HAMATE-STAGE 2 |
| | M | 26 | 1( 3.8) | 1( 3.8) | 8(30.8) | 15(57.7) | 1( 3.8) | | | * |
| | F | 17 | | 4(23.5) | 4(23.5) | 8(47.1) | 1( 5.9) | | | * |
| HAMATE-Stage 2 n-gn | | | | | | | | | | HAMATE-STAGE 2 |
| | M | 23 | No significant difference in the timing of the two events | | | | | | | |
| | F | 11 | | 3(27.3) | 3(27.3) | 5(45.4) | | | | * |
| HAMATE-Stage 2 id-gn | | | | | | | | | | HAMATE-STAGE 2 |
| | M | 22 | | 2( 9.1) | 8(36.4) | 10(45.4) | 2( 9.1) | | | * |
| | F | 10 | | 3(30.0) | 4(40.0) | 3(30.0) | | | | * |
| HAMATE-Stage 2 pr-id | | | | | | | | | | HAMATE-STAGE 2 |
| | M | 18 | No significant difference in the timing of the two events | | | | | | | |
| | F | 10 | 1(10.0) | 2(20.0) | 4(40.0) | 3(30.0) | | | | * |

* Time difference between paired events significant at $p < .05$

** Time difference between paired events significant at $p < .01$

TABLE 31(b)

| Paired Events | Subject | Number | Classification of Time Interval -3 N (%) | -2 N (%) | -1 N (%) | 0 N (%) | 1 N (%) | 2 N (%) | 3 N (%) | Earliest Occurring Event |
|---|---|---|---|---|---|---|---|---|---|---|
| HAMATE-Stage 2 | | | | | | | | | | HAMATE-STAGE 2 |
| pm-s | M | 22 | No significant difference in the timing of the two events | | | | | | | |
| | F | 16 | | 2(12.5) | 9(56.3) | 5(31.2) | | | | ** SESAMOID |
| SESAMOID/n-s | M | 26 | No significant difference in the timing of the two events | | | | | | | |
| | F | 19 | 1( 5.3) | 1( 5.3) | 9(47.3) | 7(36.8) | 1( 5.3) | | | ** |
| SESAMOID/pg-ar | M | 26 | 1( 3.8) | 2( 7.7) | 7(26.9) | 14(53.9) | 2( 7.7) | | | SESAMOID * |
| | F | 16 | No significant difference in the timing of the two events | | | | | | | |
| SESAMOID/pg-go | M | 28 | 1( 3.6) | 1( 3.6) | 8(28.5) | 18(64.3) | | | | SESAMOID ** |
| | F | 18 | | 4(22.2) | 6(33.3) | 7(38.9) | 1( 5.6) | | | * SESAMOID |
| SESAMOID/n-gn | M | 25 | No significant difference in the timing of the two events | | | | | | | |
| | F | 12 | | 2(16.7) | 4(33.3) | 6(50.0) | | | | * |

* Time difference between paired events significant at $p < .05$

** Time difference between paired events significant at $p < .01$

TABLE 31(c)

| Paired Events | Subject Number | | Classification of Time Interval -3 N (%) | -2 N (%) | -1 N (%) | 0 N (%) | 1 N (%) | 2 N (%) | 3 N (%) | Earliest Occurring Event |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | SESAMOID |
| SESAMOID/id-gn | M | 24 | 1( 4.2) | 1( 4.2) | 7(29.1) | 14(58.3) | 1( 4.2) | | | * |
| | F | 11 | | 1( 9.1) | 7(63.6) | 3(27.3) | | | | ** |
| | | | | | | | | | | SESAMOID |
| SESAMOID/pr-id | M | 20 | No significant difference in the timing of the two events | | | | | | | |
| | F | 10 | 1(10.0) | 2(20.0) | 3(30.0) | 4(40.0) | | | | * |
| | | | | | | | | | | SESAMOID |
| SESAMOID/pm-s | M | 25 | No significant difference in the timing of the two events | | | | | | | |
| | F | 18 | | 3(16.7) | 9(50.0) | 5(27.8) | 1( 5.5) | | | ** |

* Time Difference between paired events significant at $p < .05$

** Time Difference between paired events significant at $p < .01$

TABLE 32. Time intervals recorded in decimal years, based on chronological age, between carpal ossification events in 50 males and 32 females.

| Paired Events | Subject | Number | Classification of Time Interval -3 N (%) | -2 N (%) | -1 N (%) | 0 N (%) | 1 N (%) | 2 N (%) | 3 N (%) | Earliest Occurring Event |
|---|---|---|---|---|---|---|---|---|---|---|
| PISIFORM | | | | | | | | | | PISIFORM |
| HAMATE-Stage 2 | M | 32 | 2( 6.3) | 5(15.6) | 13(40.6) | 12(37.5) | | | | ** |
| | F | 21 | 1( 4.8) | 3(14.3) | 10(47.6) | 6(28.5) | 1( 4.8) | | | ** |
| PISIFORM | | | | | | | | | | PISIFORM |
| SESAMOID | M | 37 | 2( 5.4) | 5(13.5) | 16(43.2) | 14(37.8) | | | | ** |
| | F | 24 | 1( 4.2) | 3(12.5) | 12(50.0) | 6(25.0) | 2(8.3) | | | ** |
| PISIFORM | | | | | | | | | | PISIFORM |
| SESAMOID-Stage 1 | M | 5 | No significant difference in the timing of the two events | | | | | | | |
| | F | 9 | | 2(22.2) | 4(44.4) | 3(33.3) | | | | * |
| PISIFORM | | | | | | | | | | PISIFORM |
| SESAMOID-Stage 2 | M | 16 | 1( 6.2) | 2(12.5) | 8(50.0) | 5(31.3) | | | | ** |
| | F | 13 | 2(15.4) | 2(15.4) | 7(53.8) | 1( 7.7) | 1( 7.7) | | | ** |
| PISIFORM | | | | | | | | | | PISIFORM |
| SESAMOID Stage 3 | M | 21 | 2( 9.5) | 5(23.8) | 8(38.1) | 6(28.6) | | | | ** |
| | F | 17 | 2(11.8) | 7(41.2) | 4(23.5) | 3(17.6) | 1( 5.9) | | | ** |

* Time difference between paired events significant at $p < .05$

** Time difference between paired events significant at $p < .01$

TABLE 32 (continued)

| Paired Events | Subject Number | | Classification of Time Interval -3 N (%) | -2 N (%) | -1 N (%) | 0 N (%) | 1 N (%) | 2 N (%) | 3 N (%) | Earliest Occurring Event |
|---|---|---|---|---|---|---|---|---|---|---|
| HAMATE-Stage 1 HAMATE-Stage 2 | | | | | | | | | | HAMATE-STAGE 1 |
| | M | 21 | 2( 9.5) | 5(23.8) | 14(66.7) | | | | | ** |
| | F | 15 | | 3(20.0) | 11(77.3) | 1( 6.7) | | | | ** |
| HAMATE-STAGE 1 SESAMOID | | | | | | | | | | HAMATE-STAGE 1 |
| | M | 26 | 2( 7.7) | 6(23.1) | 11(42.3) | 7(26.9) | | | | ** |
| | F | 18 | | 4(22.2) | 7(38.9) | 5(27.8) | 1(11.1) | | | * |
| HAMATE-Stage 1 SESAMOID-Stage 2 | | | | | | | | | | HAMATE-STAGE 1 |
| | M | 9 | 1(11.1) | 4(44.4) | 2(22.2) | 2(22.2) | | | | * |
| | F | 9 | No significant difference in the timing of the two events | | | | | | | |
| HAMATE-Stage 1 SESAMOID-Stage 3 | | | | | | | | | | HAMATE-STAGE 1 |
| | M | 17 | 2(11.8) | 2(11.8) | 11(64.7) | 2(11.8) | | | | ** |
| | F | 12 | 2(16.7) | 2(16.7) | 4(33.3) | 4(33.3) | | | | ** |
| SESAMOID SESAMOID-Stage 3 | | | | | | | | | | SESAMOID |
| | M | 25 | No significant difference in the timing of the two events | | | | | | | |
| | F | 17 | | 3(17.6) | 7(41.2) | 7(41.2) | | | | ** |
| SESAMOID Stage 2 SESAMOID Stage 3 | | | | | | | | | | SESAMOID-STAGE 2 |
| | M | 4 | No significant difference in the timing of the two events | | | | | | | |
| | F | 9 | | | 9(100.0) | | | | | ** |

* Time difference between paired events significant at $p < .05$
** Time difference between paired events significant at $p < .01$

TABLE 33(a). Paired comparisons in which there was no significant differences between the number of subjects having one event either preceding or following the other.

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Peak velocity in stature and:

sesamoid-stage 1, sesamoid-stage 2, sesamoid-stage 3,
peak velocity in n-s, peak velocity in pm-sp,
peak velocity in pg-ar, peak velocity in pg-go,
peak velocity in ar-go, peak velocity in n-gn,
peak velocity in n-sp, peak velocity in id-gn,
peak velocity in pr-id, peak velocity in pm-s.

Pisiform ossification and:

hamate-stage 1, sesamoid-stage 1 (males only),
peak velocity in n-sp (males only)
peak velocity in pr-id (males only)
peak velocity in pm-s (males only)

Hamate-stage 1 ossification and:

sesamoid-stage 1, sesamoid-stage 2 (females only),
peak velocity in n-sp (females only),
peak velocity in id-gn (females only),
peak velocity in pr-id (males only).

Hamate-stage 2 ossification and:

sesamoid-stage 3, peak velocity in pm-sp,
peak velocity in pg-ar, peak velocity in ar-go,
peak velocity in n-gn (males only),
peak velocity in n-sp,
peak velocity in pr-id (males only),
peak velocity in pm-s (males only)

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TABLE 33(b)

Sesamoid ossification and:

sesamoid-stage 1, sesamoid-stage 2, sesamoid-stage 3 (males only), peak velocity in n-s (males only), peak velocity in pm-sp, peak velocity in pg-ar (females only), peak velocity in ar-go, peak velocity in n-gn (males only), peak velocity in n-sp, peak velocity in pr-id (males only), peak velocity in pm-s (males only).

Sesamoid-stage 1 and:

sesamoid-stage 2, sesamoid-stage 3, peak velocity in n-s, peak velocity in pm-sp, peak velocity in pg-ar, peak velocity in pg-go, peak velocity in ar-go, peak velocity in n-gn, peak velocity in n-sp, peak velocity in id-gn, peak velocity in pr-id, peak velocity in pm-s.

Sesamoid-stage 2 and:

sesamoid-stage 3 (males only), peak velocity in n-s, peak velocity in pm-sp, peak velocity in pg-ar, peak velocity in pg-go, peak velocity in ar-go, peak velocity in n-gn, peak velocity in n-sp, peak velocity in id-gn, peak velocity in pr-id, peak velocity in pm-s.

Sesamoid-stage 3 and:

peak velocity in n-s, peak velocity in pm-sp, peak velocity in pg-ar, peak velocity in pg-go, peak velocity in ar-go, peak velocity in n-gn, peak velocity in n-sp, peak velocity in id-gn, peak velocity in pr-id, peak velocity in pm-s

TABLE 33(c)

Peak velocity in n-s and:

peak velocity in pm-sp, peak velocity in pg-ar,
peak velocity in pg-go, peak velocity in ar-go,
peak velocity in n-gn, peak velocity in n-sp,
peak velocity in id-gn, peak velocity in pr-id,
peak velocity in pm-s.

Peak velocity in pm-sp and:

peak velocity in pg-ar, peak velocity in pg-go,
peak velocity in ar-go, peak velocity in n-gn,
peak velocity in n-sp, peak velocity in id-gn,
peak velocity in pr-id, peak velocity in pm-s.

Peak velocity in pg-ar and:

peak velocity in pg-go, peak velocity in ar-go,
peak velocity in n-gn, peak velocity in n-sp,
peak velocity in id-gn, peak velocity in pr-id,
peak velocity in pm-s.

Peak velocity in pg-go and:

peak velocity in ar-go, peak velocity in n-gn,
peak velocity in n-sp, peak velocity in id-gn,
peak velocity in pr-id, peak velocity in pm-s.

Peak velocity in ar-go and:

peak velocity in n-gn, peak velocity in n-sp,
peak velocity in id-gn, peak velocity in pr-id,
peak velocity in pm-s.

Peak velocity in n-gn and:

peak velocity in n-sp, peak velocity in id-gn,
peak velocity in pr-id, peak velocity in pm-s.

TABLE 33(d)

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Peak velocity in n-sp and:
peak velocity in id-gn, peak velocity in pr-id,
peak velocity in pm-s.

Peak velocity in id-gn and:
peak velocity in pr-id, peak velocity in pm-s.

Peak velocity in pr-id and:
peak velocity in pm-s.

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# DISCUSSION

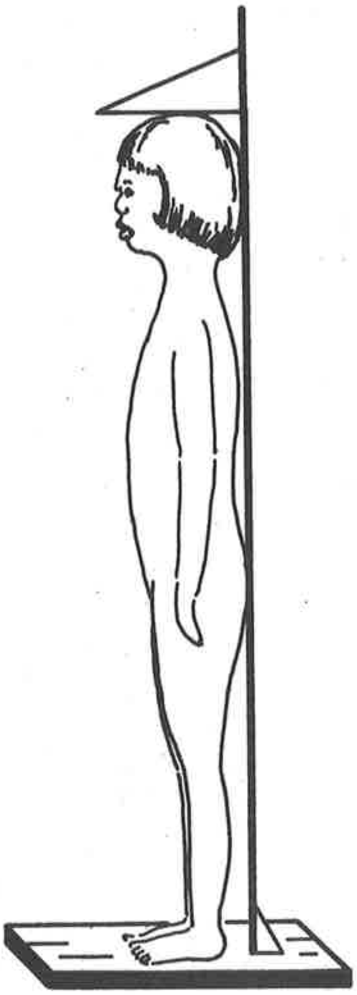
To simplify discussion, timing intervals between paired events are discussed under three main headings:

Stature - carpal ossification;

Carpal ossification - upper and lower face;

Carpal ossification.

Diagrams are used to identify the timing interval under discussion.



## STATURE - CARPAL OSSIFICATION

Table 34 (p.172 ) shows and Fig.14 (p.173 ) illustrates that in general the selected ossification events ossified either before or during the same year as peak velocity in stature. In fact, in the majority of subjects, the pisiform and hamate-stage 1 ossified before the year during which peak velocity in stature occurred.

Table 28 shows that the pisiform ossified during the year before peak velocity in stature in 54.2% of males and 68.7% of females. Moreover, in approximately 53% of females ossification of the hook of the hamate-stage 1 and ossification of the sesamoid occurred during the year before peak velocity in stature.

Ossification of the hook of the hamate-stage 2 occurred during the same year as peak velocity in stature in 65.4% of males and 60.0% of females. However, in 75.3% of males the sesamoid ossified during the same year as peak velocity in stature.

Table 34 records that mean values for the timing intervals between events in males ranged from 0.3 years for the stature/hamate-stage 2 and stature - sesamoid comparisons to 1.7 years for the stature/hamate-stage 1 comparison. In females the minimum timing interval was 0.5 years for the stature/hamate-stage 2 and stature-sesamoid comparisons, and the maximum was 1.4 years for the stature/pisiform comparison.

TABLE 34. Percentage of subjects with ossification events occurring before or after peak velocity in stature. The mean and standard deviation of the timing interval between events are listed in decimal years.

| Paired Events | | % of subjects in which the ossification event occurred BEFORE peak velocity in stature | % of subjects in which the ossification event occurred AFTER peak velocity in stature | Mean Time Interval | Standard Deviation |
|---|---|---|---|---|---|
| STATURE/PISIFORM | M | 79.2 | - | 1.3 | 1.0 |
| | F | 93.7 | - | 1.4 | 0.8 |
| STATURE/HAMATE-Stage 1 | M | 87.5 | - | 1.7 | 1.1 |
| | F | 76.9 | 7.7 | 1.2 | 1.2 |
| STATURE/HAMATE Stage 2 | M | 30.7 | 3.9 | 0.3 | 0.6 |
| | F | 40.0 | - | 0.5 | 0.7 |
| STATURE/SESAMOID | M | 26.6 | - | 0.3 | 0.5 |
| | F | 52.9 | 5.9 | 0.5 | 0.7 |

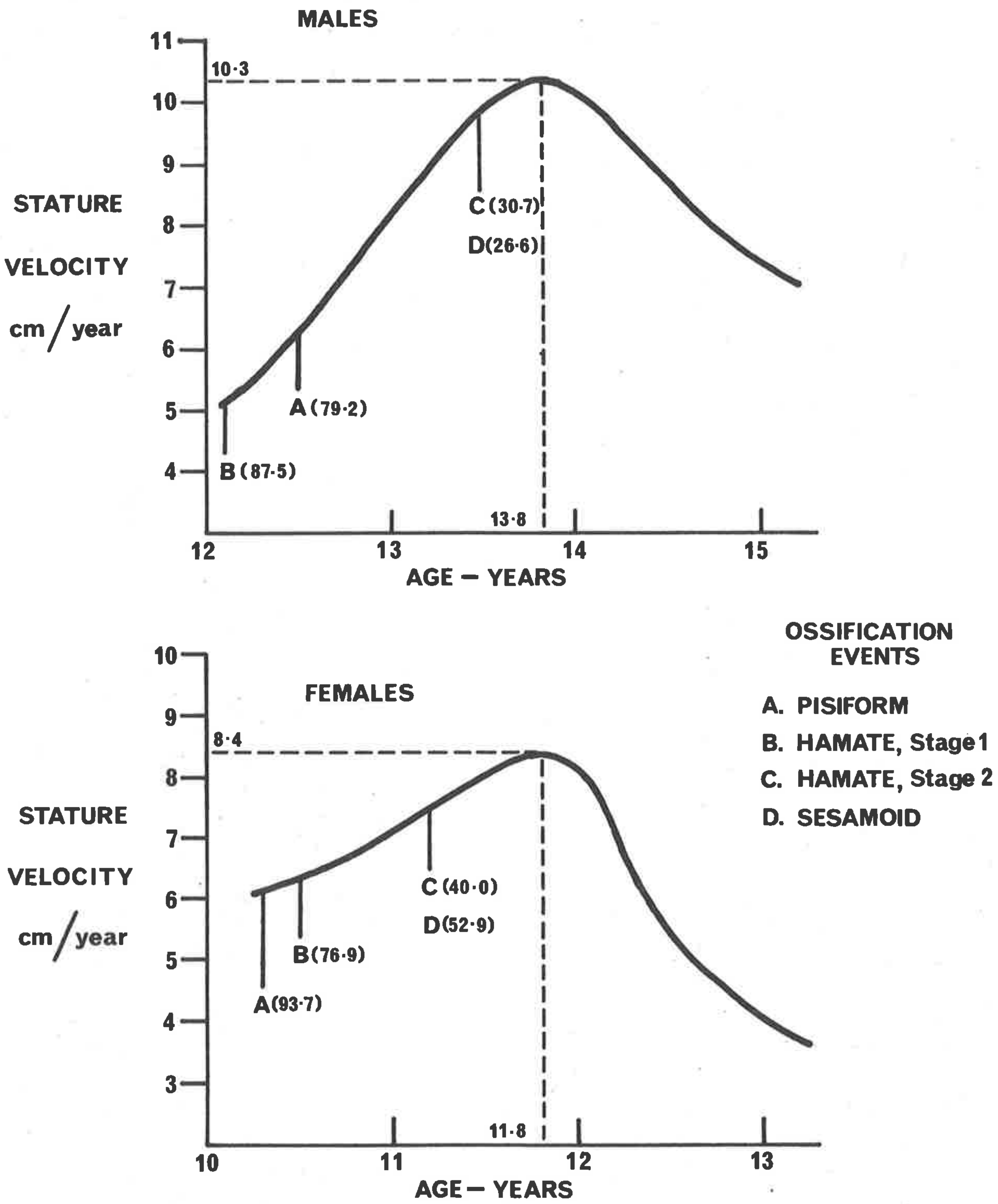
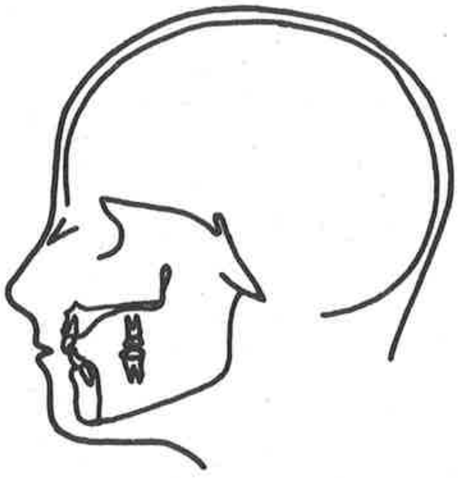



Fig. 14. Mean time interval between ossification events and peak velocity in stature.
Percentage of subjects in which ossification events occurred before peak velocity in stature shown in brackets.

## SUMMARY

The time differences between selected ossification events and peak velocity in stature have been discussed. In both males and females, the most reliable indicator of the time at which peak velocity in stature occurred was the appearance of the pisiform. In males, however, ossification of the hook of the hamate-stage 1 also seems to be a fairly reliable indicator. Ossification of the *hook* of the *hamate-stage 2,* in *males and females* and the appearance of the *sesamoid,* in *males only,* indicate that peak velocity in stature is either occurring or is imminent.



## CARPAL OSSIFICATION - UPPER FACE

Table 35 (p. 177 ) shows that in general the ossification events studied appeared either before or during the same year as peak velocity in upper facial dimensions. Ossification of the hook of the hamate-stage 1 occurred after peak velocity in variables pm-s and n-s in 13.4% of males and 15.3% of females respectively. However, in females only the pisiform showed significant timing intervals with all upper facial dimensions, and in males hamate-stage 1 occurred before peak growth in all upper facial dimensions.

On the average, ossification in hamate-stage 2 and in the sesamoid occurred before peak growth velocity in upper facial dimensions more frequently in females than in males. The mean values of the timing intervals between these two ossification events and all the upper facial peak velocities were greater in females than in males, that is in females carpal ossification preceded upper facial growth peaks by a greater time than it did in males.

In the treatment of Class II division I Malocclusion some clinicians apply a form of extraoral traction to the maxilla in order to retard its forward growth. Knowing when peak velocity is likely to occur in the maxilla is of great clinical value. Table 35 shows that ossification of the hamate-stage 1 did not occur after peak velocity in the dimension pm-sp, in either males or females and the mean value for the timing interval was 1.6 years in males and 1.3 years in females. It is interesting to note that ossification of the hamate-stage 2 was almost coincident with peak velocity in the dimension pm-sp (interval is 0.1 years in males and 0.3 years in females).

TABLE 35. Percentage of subjects with ossification events occurring before or after peak velocity in upper facial dimensions. The mean and standard deviation of the timing interval between events are listed in decimal years.

| Paired Events | % of subjects in which the ossification event occurred BEFORE peak velocity in upper facial dimension | | % of subjects in which the ossification event occurred AFTER peak velocity in upper facial dimension | | Mean Time Interval | | Standard Deviation | |
|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F |
| n-s/PISIFORM | 73.9 | 73.6 | 8.7 | 5.3 | 1.3 | 1.4 | 1.6 | 1.3 |
| n-s/HAMATE-Stage 1 | 80.1 | 77.0 | 13.3 | 15.3 | 1.6 | 1.5 | 1.6 | 1.5 |
| n-s/HAMATE-Stage 2 | 43.4 | 52.9 | 8.6 | 5.9 | 0.5 | 0.7 | 1.0 | 1.2 |
| n-s/SESAMOID | - | 57.9 | - | 5.3 | 0.4 | 0.8 | 0.9 | 1.0 |
| pm-sp/PISIFORM | 64.7 | 56.7 | 11.8 | 11.1 | 0.7 | 1.1 | 1.2 | 1.3 |
| pm-sp/HAMATE-Stage 1 | 72.8 | 69.2 | - | - | 1.6 | 1.3 | 1.6 | 1.1 |
| pm-sp/HAMATE-Stage 2 | - | - | - | - | 0.1 | 0.3 | 1.3 | 1.0 |
| pm-sp/SESAMOID | - | - | - | - | 0.2 | 0.3 | 1.3 | 0.9 |
| n-gn/PISIFORM | 73.9 | 90.9 | 8.7 | - | 1.3 | 1.9 | 1.4 | 1.0 |
| n-gn/HAMATE-Stage 1 | 78.6 | 88.8 | 7.1 | 11.1 | 1.6 | 1.6 | 1.5 | 1.2 |
| n-gn/HAMATE-Stage 2 | - | 54.6 | - | - | 0.5 | 0.8 | 1.1 | 0.9 |
| n-gn/SESAMOID | - | 50.0 | - | - | 0.4 | 0.7 | 1.0 | 0.8 |

TABLE 35 (continued)

| Paired Event | % of subjects in which the ossification event occurred BEFORE peak velocity in upper facial dimension | | % of subjects in which the ossification event occurred AFTER peak velocity in upper facial dimension | | Mean Time Interval | | Standard Deviation | |
|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F |
| n-sp/PISIFORM | - | 75.0 | - | - | 0.6 | 1.8 | 2.0 | 1.7 |
| n-sp/HAMATE-Stage 1 | 64.6 | - | 11.8 | - | 0.9 | 1.3 | 1.9 | 1.9 |
| n-sp/HAMATE-Stage 2 | - | - | - | - | 0.3 | 0.7 | 1.7 | 2.0 |
| n-sp/SESAMOID | - | - | - | - | 0.3 | 0.8 | 1.8 | 1.9 |
| pm-s/PISIFORM | - | 77.8 | - | 5.5 | 0.8 | 1.4 | 2.1 | 1.6 |
| pm-s/HAMATE-Stage 1 | 79.9 | 83.3 | 13.4 | 8.3 | 1.3 | 1.8 | 2.0 | 1.3 |
| pm-s/HAMATE-Stage 2 | - | 68.8 | - | - | 0.3 | 0.9 | 1.1 | 0.7 |
| pm-s/SESAMOID | - | 66.7 | - | 5.5 | 0.1 | 0.9 | 1.3 | 0.9 |

## CARPAL OSSIFICATION - LOWER FACE

Table 36 (p. 180 ) shows that in the majority of subjects the ossification events under study appeared either before or during the same year as peak velocity in lower facial dimensions. In fact, ossification events occurred after peak velocities in only 12 out of a total of 40 paired comparisons. In at least 75% of subjects ossification of the pisiform and hamate-stage 1 occurred before peak velocity in most lower facial dimensions. The average time interval between these two ossification events and the lower facial dimensions ranged from 0.6 - 2.5 years in males and 1.4 - 2.4 years in females.

Peak velocities of the variables id-gn and pr-id occurred after the appearance of hamate-stage 2 and the sesamoid in a greater percentage of females than males. The sex difference in the time interval between events id-gn and hamate-stage 2 was 0.5 years and for the events id-gn and sesamoid, 0.4 years; for the events pr-id and hamate-stage 2 and pr-id and sesamoid the sex difference in the mean time intervals was 1.0 years in each instance. In males, the range of the mean time interval between hamate-stage 2 and sesamoid, and lower facial dimensions was 0.2 - 0.5 years, and in females 0.6 - 1.3 years.

TABLE 36. Percentage of subjects with ossification events occurring before or after peak velocity in lower facial dimensions. The mean and standard deviation of the timing interval between events are listed in decimal years.

| Paired Events | % of subjects in which the ossification event occurred BEFORE peak velocity in various lower facial dimensions | | % of subjects in which the ossification event occurred AFTER peak velocity in various lower facial dimensions | | Mean Time Interval | | Standard Deviation | |
|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F |
| pg-ar/PISIFORM | 75.0 | 80.0 | 4.2 | - | 1.3 | 1.6 | 1.3 | 1.0 |
| pg-ar/HAMATE-Stage 1 | 87.5 | 81.8 | - | - | 1.8 | 1.4 | 1.2 | 0.8 |
| pg-ar/HAMATE-Stage 2 | - | - | - | - | 0.5 | 0.6 | 1.0 | 1.1 |
| pg-ar/SESAMOID | 38.4 | - | 7.7 | - | 0.5 | 0.6 | 1.0 | 1.0 |
| pg-go/PISIFORM | 81.8 | 78.9 | - | 5.3 | 1.5 | 1.4 | 1.2 | 1.4 |
| pg-go/HAMATE-Stage 1 | 87.5 | 92.3 | - | - | 1.9 | 1.6 | 1.1 | 0.8 |
| pg-go/HAMATE-Stage 2 | 38.4 | 47.0 | 3.8 | 5.9 | 0.5 | 0.7 | 0.8 | 1.0 |
| pg-go/SESAMOID | 35.7 | 55.5 | - | 5.6 | 0.5 | 0.8 | 0.7 | 1.0 |
| ar-go/PISIFORM | 76.2 | 86.6 | 4.8 | 6.7 | 1.6 | 1.5 | 1.9 | 1.0 |
| ar-go/HAMATE-Stage 1 | 100.0 | 80.0 | - | 10.0 | 2.5 | 1.5 | 1.5 | 1.3 |
| ar-go/HAMATE-Stage 2 | - | - | - | - | 0.4 | 0.7 | 1.7 | 1.1 |
| ar-go/SESAMOID | - | - | - | - | 0.4 | 0.7 | 1.6 | 1.2 |

TABLE 36 (continued)

| Paired Event | % of subjects in which the ossification event occurred BEFORE peak velocity in various lower facial dimensions | | % of subjects in which the ossification event occurred AFTER peak velocity in various lower facial dimensions | | Mean Time Interval | | Standard Deviation | |
|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F |
| id-gn/PISIFORM | 80.0 | 91.0 | 5.0 | - | 1.4 | 1.2 | 1.3 | 1.2 |
| id-gn/HAMATE-Stage 1 | 83.3 | - | - | - | 2.1 | 2.1 | 1.3 | 1.5 |
| id-gn/HAMATE-Stage 2 | 45.5 | 70.0 | 9.1 | - | 0.5 | 1.0 | 0.8 | 0.9 |
| id-gn/SESAMOID | 37.5 | 72.7 | 4.2 | - | 0.5 | 0.9 | 0.8 | 0.7 |
| pr-id/PISIFORM | - | 100.0 | - | - | 0.6 | 2.4 | 1.4 | 0.6 |
| pr-id/HAMATE-Stage 1 | - | 100.0 | - | - | 1.0 | 2.3 | 1.6 | 0.4 |
| pr-id/HAMATE-Stage 2 | - | 70.0 | - | - | 0.3 | 1.3 | 1.1 | 1.8 |
| pr-id/SESAMOID | - | 60.0 | - | - | 0.2 | 1.2 | 1.7 | 1.4 |

## SUMMARY

The timing of various ossification events have been discussed in relation to the time of peak velocity in upper and lower facial dimensions. In males the time of appearance of the hook of the hamate-stage 1 and in females, the time of appearance of the pisiform seem to be the best indicators of the onset of peak velocity in facial dimensions. The pisiform appears on the average in males and females 1.5 years before peak velocity in the upper face and 1.8 years before peak velocity in the lower face. However, hamate-stage 1 appears on the average in males and females 1.4 years and 1.8 years before peak velocity in the upper and lower face respectively.

# CARPAL OSSIFICATION

## PISIFORM/HAMATE-STAGE 2.

The pisiform ossified before the hook of the hamate-stage 2 in 62.5% of males and 66.7% of females (Table 37). In one female the pisiform ossified during the year following ossification of the hook of the hamate-stage 2 (Table 32).

## PISIFORM/SESAMOID.

The pisiform ossified before the ulna metacarpophalangeal sesamoid of the thumb in 62.2% of males and 66.7% of females (Table 37). In 50% of females the pisiform ossified during the year before the sesamoid appeared. However, in two females (8.3%) the pisiform ossified during the year following the sesamoid appearance (Table 32).

## PISIFORM/SESAMOID STAGES

In 50% of males and 53.8% of females the pisiform ossified during the year before Stage 2 level of the ulna metacarpophalangeal sesamoid of the thumb was reached (Table 32).

## HAMATE-STAGE 1/HAMATE-STAGE 2

Stage 1 in the ossification of the hook of the hamate occurred during the year before Stage 2 in 66.7% of males and 77.3% of females. In two males (9.5%) the interval between stages was greater than 2.5 years (Table 32).

TABLE 37. Percentage of subjects with significant differences in the intervals between various ossification events. The mean and standard deviation of the timing interval between events are listed in decimal years.

| Paired Event | % of subjects in which the first listed ossification event appeared BEFORE the second | | % of subjects in which the first listed ossification event appeared AFTER the second | | Mean Time Interval | | Standard Deviation | |
|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F |
| PISIFORM/HAMATE-Stage 2 | 62.5 | 66.7 | - | 4.8 | -1.0 | -0.9 | 0.9 | 1.0 |
| PISIFORM/SESAMOID | 62.2 | 66.7 | - | 8.3 | -0.9 | -0.8 | 0.9 | 1.1 |
| PISIFORM/SESAMOID-Stage 1 | - | 66.6 | - | - | -0.4 | -0.9 | 0.6 | 0.9 |
| PISIFORM/SESAMOID-Stage 2 | 68.7 | 84.6 | - | 7.7 | -1.0 | -1.3 | 0.9 | 1.2 |
| PISIFORM/SESAMOID-Stage 3 | 71.4 | 76.5 | - | 5.9 | -1.2 | -1.4 | 1.0 | 1.3 |
| HAMATE-Stage 1/ HAMATE-Stage 2 | 100.0 | 93.3 | - | - | -1.5 | -1.3 | 0.7 | 0.6 |
| HAMATE-Stage 1/ SESAMOID | 73.1 | 61.1 | - | 11.1 | -1.2 | -0.8 | 0.9 | 1.0 |
| HAMATE-Stage 1/ SESAMOID-Stage 2 | 77.7 | - | - | - | -1.5 | -0.8 | 1.0 | 1.4 |
| HAMATE-Stage 1/ SESAMOID-Stage 3 | 88.2 | 77.7 | - | - | -1.3 | -1.3 | 0.9 | 1.2 |

TABLE 37 (Continued)

| Paired Events | % of subjects in which the first listed ossification event appeared BEFORE the second | | % of subjects in which the first listed ossification event appeared AFTER the second | | Mean Time Interval | | Standard Deviation | |
|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F |
| SESAMOID/ SESAMOID-Stage 3 | - | 58.8 | - | - | -0.3 | -0.8 | 0.5 | 0.8 |
| SESAMOID-Stage 2/ SESAMOID-Stage 3 | - | 100.0 | - | - | - | -1.0 | - | 0.1 |

HAMATE-STAGE 1/SESAMOID

Ossification of the hook of the hamate-stage 1 occurred before the appearance of the ulna metacarpophalangeal sesamoid of the thumb in 73.1% of males and 61.1% of females (Table 37).

HAMATE-STAGE 1/SESAMOID STAGES

Ossification of the hook of the hamate-stage 1 occurred during the year before the appearance of sesamoid-stage 3 in 64.7% of males (Table 32).

SESAMOID/SESAMOID STAGES

In all females, sesamoid-stage 2 was reached during the year before sesamoid-stage 3 (Table 32).

## SUMMARY

The timing intervals between various ossification events have been discussed. In males the pisiform appeared before or during the same year as all other ossification events except ossification of the hook of the hamate-stage 1. However, in a small percentage of females, the pisiform ossified after hamate-stage 2, the initial appearance of the sesamoid and sesamoid-stage 2 and stage 3. Also, in a small group of females, ossification of the hook of the hamate-stage 1 was seen to occur after the initial appearance of the sesamoid.

CHAPTER VIII

# GENERAL DISCUSSION AND CONCLUSIONS

Since 1951 regular expeditions have been made to the Yuendumu Settlement, in the Northern Territory of Australia, by members of the Department of Dental Science, University of Adelaide. The early expeditions were mainly concerned with the collection of serial dental casts and the study of dental and oral conditions in Aborigines. However, in 1961 the scope of the study was broadened so that craniofacial growth could be related to certain aspects of skeletal maturation and general body growth in the subjects. As a result, hand and wrist roentgenograms, dental casts, cephalometric roentgenograms, and selected body measurements were obtained annually.

The subjects enrolled in the longitudinal growth study belong mainly to the Wailbri tribe of Australian Aborigines. It could be said that culturally they are still tribally orientated, although European influence has imposed different environmental conditions. However, one advantage of this study is that the group forms a relatively isolated and distinctly inbred community. Many of the difficulties encountered when studying growth in a heterogenous group are then avoided.

The present report is restricted to a study of serial hand and wrist, and lateral head roentgenograms as well as serial stature measurements of 50 males and 36 females, aged 8 - 18 years. Most belong to the Wailbri tribe, although a few Pintubi children are included in the group. All subjects were of pure Aboriginal ancestry so far as can be ascertained.

In the first part of the study the time of appearance of carpal ossification events was determined. The time of appearance was recorded as the mid-point of the year in which each event occurred.

In the second part of the study the times of peak growth velocity in height and facial dimensions were determined. Age was recorded as the mid-point of the year during which peak growth velocity in height and in each facial measurement occurred. In the facial skeleton, variables were selected for measurement so that several dimensions of the nasomaxillary complex were represented.

A computer was used to determine correlation coefficients between the variables included in the study and to study the relations in time between paired events. In the text, the importance of *careful interpretation of coefficients of linear correlation* has been emphasized. This was stressed in relation to paired combinations of cephalometric variables "topographically" related and to paired combinations between age-associated events.

For convenience, the results are summarized under the following headings:

Ossification events;

Peak growth velocity in stature and the facial skeleton;

Relations between ossification events, stature and facial growth.

## Ossification Events

Of the ossification events studied in Aborigines, the earliest events recorded on serial hand and wrist roentgenograms were the initial ossification of the pisiform and the hook of the hamate. *Hamate-stage 1* appeared at *10.6 years in females* and *12.2 years in males;* and the age-at-appearance of the *pisiform* was *10.5 years in females* and *12.6 years in males.* Ossification of the adductor *sesamoid* of the thumb, which was the last event to appear, occurred at *11.2 years in females* and *13.5 years in males.*

All ossification events occurred earlier in females than in males. Ossification in the hamate-stage 2 and in the sesamoid showed the greatest time difference between sexes (2.3 years). This value is similar to that reported by GREULICH and PYLE ('59), GARN and ROHMANN ('62) and BJÖRK and HELM ('67). The smallest time difference between sexes (1.6 years) was recorded for hamate-stage 1; this value approximates that given by ABBIE and ADEY ('53b) for Aborigines and GREULICH and PYLE ('59) for Caucasoids.

The ages-at-appearance of the carpal ossification events studied showed that although Aborigines were placed within the general Caucasoid range of development timing, Aboriginal times were a little later, on the average, than those for Caucasoids.

## Peak Velocity in Stature and Facial Skeleton

The magnitude of peak growth velocity in stature (*Aboriginal males)* was found to be the same *(10.3 cm/year)* as that recorded for British males by TANNER, WHITEHOUSE and TAKAISHI ('66). However, in *Aboriginal females,* the value *(8.5 cm/year)* was slightly less than that for British females (9.1 cm/year, TANNER et al, '66). *Peak growth velocity* occurred at mean age *13.8 years and 11.8 years in Aboriginal males and females respectively.* These times fell midway between the average ages given for British (TANNER et al, '66) and North American (DEMING, '57) children. However, the sex difference in the age at peak height velocity (2.0 years) corresponded to the value mentioned in the above reports.

In general, maximum growth velocity in the facial skeleton was greater in Aboriginal males than in Aboriginal females. Similar findings were reported in Caucasoids by NANDA ('55) and BAMBHA ('61). Aboriginal females reached their peak velocity in the facial skeleton earlier than Aboriginal males. The maximum sex difference in the age at peak velocity was 2.0 years for the measurement, mandibular body length (pg-go) and the minimum sex difference was 0.7 years for the measurement middle face height (pr-id). BAMBHA ('61) stated that in females the face tended to mature 2 - 3 years earlier than in males. However, BAMBHA used different facial measurements to those used in the present study, so that close comparison of the two studies is not warranted.

Maximum growth in the length of the maxilla (pm-sp) *(13.5 years in males and 11.7 years in females)* occurred before peak velocity in stature (Figure 15) in both sexes. The mean age in Aboriginal females (11.7 years) corresponds closely to the value of 11.5 years given by SINGH and SAVARA ('66) for Caucasoid females. *The last event to occur in Aboriginal females was peak velocity in mandibular face height.* This occurred on the average 0.9 years after peak velocity

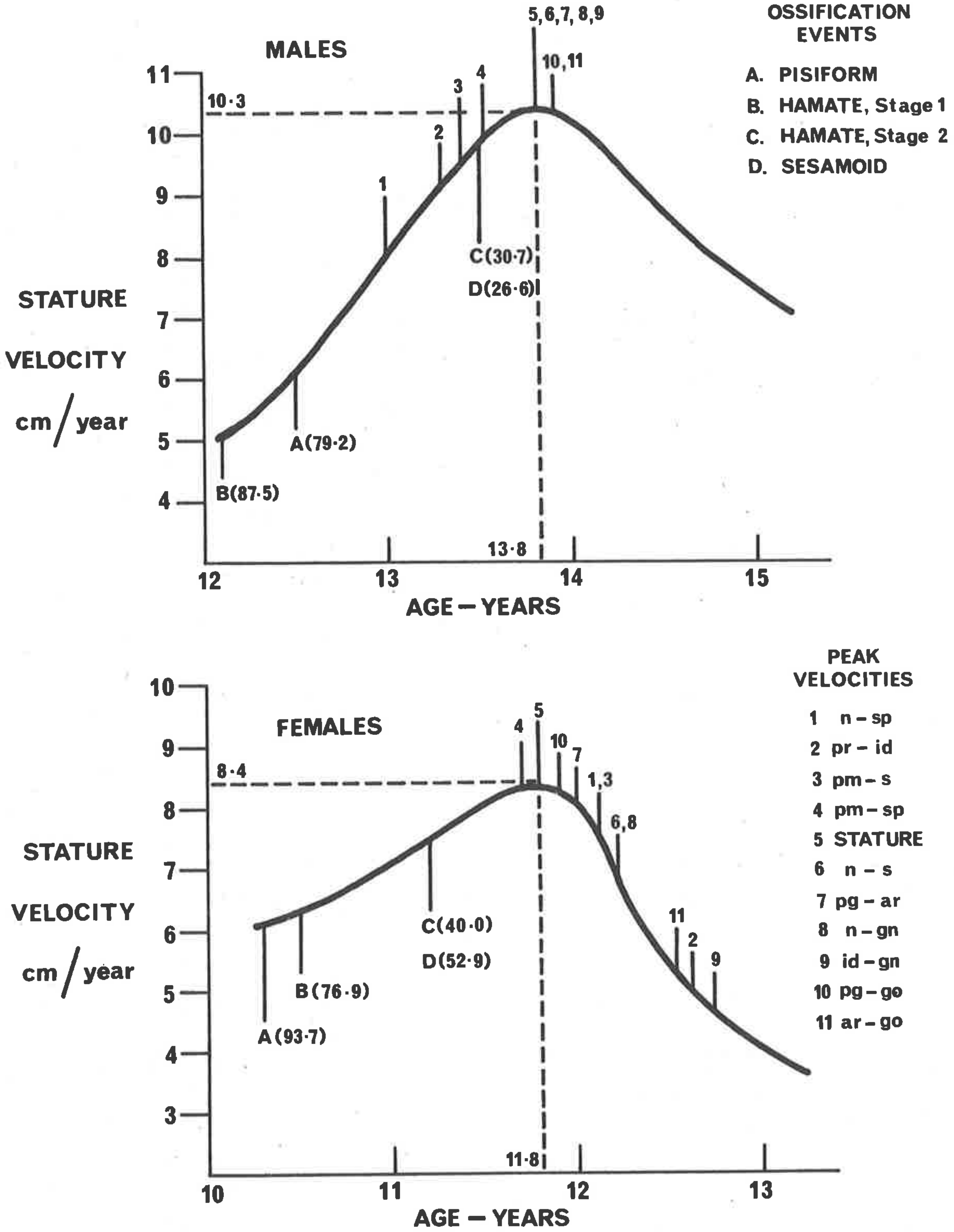



Fig. 15. Mean time interval between ossification events and peak velocity in stature and facial dimensions. Percentage of subjects in which ossification events occurred before peak velocity in stature shown in brackets (Detail analysis of these ossification events are shown in Tables 28, 34).

in stature. In general, peak velocities of facial height measurements in Aboriginal males occurred before peak velocity in stature; furthermore, peak velocities of mandibular measurements in Aboriginal males all occurred either at the same time or slightly after peak velocity in stature.

Figure 15 clearly illustrates the time spread of peak growth velocity in measurements of the facial skeleton in relation to peak growth velocity in stature. NANDA ('55) and BAMBHA ('61) found that peak growth velocity in the face occurred a little after peak growth velocity in stature, whereas HUNTER ('66) showed that maximum facial growth was coincident with maximum growth in stature. The present study, therefore, does not reveal any great differences in the character of facial growth at adolescence between Australian Aborigines and the Caucasoid groups studied.

Relation between ossification events, stature and facial growth.

In both Aboriginal males and females associations between the chronological ages-at-appearance of the sesamoid and peak growth velocity in stature were high (the average value calculated by z-transformation, r = 0.84); however, the sesamoid timing was only moderately correlated with chronological age at peak growth velocity in most facial dimensions. Nevertheless, moderate to high coefficients of correlation were found between chronological ages at peak velocity in stature and peak velocity in most facial measurements.

Coefficients of correlation revealed a general low relationship between the magnitude of peak velocity in most facial dimensions.

However, a stronger relationship existed between the chronological ages at peak velocity in facial measurements.

In general, the selected ossification events appeared either before or during the same year as peak growth velocity in stature. The *pisiform* ossified before peak velocity in stature in *93.7% of females* and *hamate-stage 1* ossified before peak velocity in stature in *87.5% of males*. Moreover, hamate-stage 2 (in males and females) and the sesamoid (in males only) ossified during the same year as peak velocity in stature in approximately 60 - 75% of subjects.

In *females* the *pisiform ossified* on the average *1.4 years before peak growth velocity in stature* and in *males, hamate-stage 1 ossified 1.7 years before peak growth velocity in stature.* However, in both males and females, hamate-stage 2 and the sesamoid ossified approximately 0.4 years before peak velocity in stature.

In the facial skeleton the same general timing relation outlined above existed between carpal ossification events and peak velocity of upper and lower facial measurements. Ossification of *hamate-stage 1 occurred before peak velocity in the facial measurement pm-sp, in both males and females.* The average *timing interval* was *1.6 years* in *males* and *1.3 years* in *females.* It is interesting to note that ossification of hamate-stage 2 and the sesamoid was almost coincident with peak velocity in the facial measurement, pm-sp, in both males and females.

*　　*　　*　　*

Skeletal age ratings have useful clinical applications in the prediction of adult stature, in legal situations, in population studies, in paediatrics, and in studies of child growth and development.

In Orthodontic practice skeletal age ratings determined at the initial consultation could be of great assistance in locating the position of the child in relation to his progress towards maturity. Knowing the child's present growth status would assist in the planning of treatment and in the general organization of an orthodontic practice. For instance, if the pisiform *(mean age-at-appearance 10.5 years in females)* was not present in an eleven-year-old girl at the initial consultation, by applying the finding that the pisiform ossified on the average approximately 1.5 years before peak growth velocities, then it would be advisable to recall the child in one year for a further examination of pisiform development. If the pisiform was present at this second examination, then it would be reasonable to assume that its ossification occurred midway between 11 years and 12 years, that is 11.5 years. The clinician would then be in a much better position to determine the time of treatment, that is, he would commence treatment to take advantage of peak growth velocity which on the average would occur during the coming year.

Skeletal assessment could be of great benefit in determining the form of orthodontic treatment. For instance , in the treatment of Class II division I Malocclusion some clinicians apply extraoral traction to the maxilla in order to retard its forward growth. Knowing when peak velocity is likely to occur in the maxilla is of great clinical value. Results of the present study showed that in both Aboriginal males and females hamate-stage 1 did not occur after peak growth velocity in the measurement, maxillary jaw base length (pm-sp). As mentioned previously in this chapter, the average time interval between these two events in males was 1.6 years and in females 1.3 years. Such knowledge would benefit individual treatment as well as overall practice organization.

In order to illustrate further the use of hand and wrist roentgenograms in orthodontic practice, the example can be cited of a girl presenting for examination with the pisiform, hamate-stage 2 and the sesamoid already ossified but with some of the epiphyses of the distal phalanges of the fingers beginning to fuse. SINCLAIR(p.82, '69) stated "*the menarche nowadays occurs within a chronological age range of 10 - 16 years, but within a much narrower range of radiological age - from 12 to 14½ years, round about the time of fusion of the epiphyses of the terminal phalanges of the fingers.*" Menarche occurs almost invariably after the apex of the height spurt has been passed (DEMING, '59) and the present study has shown that in Aboriginal females peak growth velocity of several facial measurements occur well after peak growth velocity in stature. If the epiphyses of all terminal phalanges have fused then the indication is that peak growth velocity in stature and the facial skeleton has almost certainly passed and little further facial growth would be expected to assist treatment.

Some clinicians after active treatment use fixed retention in the lower arch in the form of a lingual bar from canine to canine. This appliance is cemented in position and retained until the child has accomplished facial maturity. SINCLAIR (p.76, '69) states that *"skeletal maturation usually proceeds roughly parallel with skeletal growth, and of course, maturation and growth both come to an end when the epiphyses close".* A hand and wrist roentgenogram would indicate if epiphyseal fusion of the long bones of the hand and wrist has occurred thereby assisting in the determination of the degree of facial maturity.

This study is an extension of the research topic reported by BJÖRK and HELM ('67). At the present time, there have been no similar studies reported in detail. The findings of the present investigation have included information on the time intervals between peak growth velocity in a number of dimensions of the nasomaxillary complex, peak growth velocity in stature and the times at which certain carpal ossification events took place.

The findings have also clarified the understanding of general relations between body growth, skeletal maturation and facial growth. In particular, the results can be applied in orthodontic practice to acquire a deeper appreciation of the growth status of patients and to more objectively plan and carry out treatment goals.

## APPENDICES

# APPENDIX A

## Dental State of the Subjects

In 1970, an oral health survey was carried out on the children and young adults at the Yuendumu Settlement (BARRETT, WILLIAMSON, BROWN and TOWNSEND, '70). Seventy-seven subjects out of the total of 82 included in the present study were examined on this expedition and the following characteristics were noted: teeth missing, teeth, unerupted, teeth with caries, teeth with restorations, enamel hypoplasia, dental fluorosis, tooth attrition, oral hygiene and periodontal condition. Observations on some of these characteristics for the remaining five subjects of this investigation were made from dental casts by the writer.

This information has been included to indicate the general dental state of Aborigines living under settlement conditions. It is important to note that no detailed information on the oral health of subjects enrolled in the present study was available prior to the 1970 survey.

Included in the number of teeth present were all erupted and partly erupted teeth. Table 38 summarizes the presence and absence of teeth in the group under investigation. Disregarding the eruption pattern of third molars, missing teeth were noted in 11 subjects (13.4%). This number included two subjects each with a missing first molar due to caries, and nine male subjects (17.3%) with a missing incisor tooth through ceremonial evulsion. CAMPBELL ('25) found evidence of ceremonial evulsion in 11.4% and BROWN ('65) noted the occurrence in 25% of males investigated.

The papers referred to in Chapter II discussed the low caries incidence at the Yuendumu Settlement. Tables 39(a) and 39(b) list the number of subjects with caries as well as the tooth surface on which the caries originated.

Caries was considered to be present when any lesion had a detectably softened floor or wall or undermined enamel. In order to establish the presence of interproximal lesions, the probe must enter the lesion with certainty. In any doubt existed, caries was not diagnosed. White spots, discoloured or rough spots, and hard stained pits or fissures which catch an explorer but do not have a detectably softened floor or undermined enamel were not counted as caries.

It is interesting to note that caries was recorded in only 37.8% of subjects in the present study and that of the total number of 78 carious lesions, 53 (67.9%) originated on a buccal surface. The small number of amalgam restorations (Table 40) emphasized the low caries incidence.

The bore water used by the Aborigines at Yuendumu contains approximately 1.5 parts per million fluoride (BARRETT,'53a, '56b). Since that report the fluoride content has increased slightly. Analyses showed the bore water contained 1.73 parts per million fluoride in 1969 and 1.93 parts per million fluoride in 1970. However, since 1965 a different bore has been used for drinking purposes and analyses showed it contains approximately 0.4 parts per million fluoride (WILLIAMSON. BARRETT, BROWN and TOWNSEND, '70). DEAN's method ('34) was used in assessing the prevalence of dental fluorosis. Table 41 shows that moderate and severe dental fluorosis was present in 39 subjects (47.6%).

Fluorosis was more prevalent in males.

Enamel hypoplasia was recorded in a total of four subjects, all were females.

An assessment of the degree of occlusal attrition was made for each subject from an examinaton of the maxillary and mandibular first permanent molars. If any of these teeth was missing, no alternative tooth was examined. Evaluation of the degree of attrition was made according to the method of DAVIES and PEDERSON ('55) and each subject was categorised into the following groups: 0 - no attrition; 1 - enamel worn without exposure of dentine; 2 - dentine exposed; 3 - secondary dentine exposed. An attrition index was derived for each subject by dividing the total scores by the number of teeth examined. Table 42 shows that the attrition index was higher in males than in females.

Oral hygiene status was determined by obtaining oral debris and calculus scores separately. Examination was limited to six permanent teeth surfaces - the labial surface of the upper right central incisor, the labial surface of the lower left central incisor, and the buccal surfaces of the upper first permanent molars. The periodontal index developed by RUSSELL ('65) was utilized to assess the prevalence and severity of periodontal disease. WILLIAMSON ('70) stated that almost all subjects were found to have gross debris in the mouth and large amounts of subgingival calculus. It appeared that the subgingival calculus formed soon after eruption and as a result a generalized gingival hyperplasia was most evident. However, the gingival hyperplasia tended to be non-progressive.

TABLE 38. (a) Dental state of the subjects studied according to the number of teeth present.

| Number of teeth present | Males | Females | Total |
|---|---|---|---|
| 32 | 6 | 8 | 14 |
| 31 | 3 | 4 | 7 |
| 30 | 3 | 1 | 4 |
| 29 | 6 | - | 6 |
| 28 | 28 | 17 | 45 |
| 27 | 4 | 1 | 5 |
| 24 | - | 1 | 1 |
| Total | 50 | 32 | 82 |

TABLE 38. (b) Dental state of the subjects studied according to the number and type of teeth missing.

| Number and type of missing teeth | Males | Females | Total |
|---|---|---|---|
| Four third molars unerupted | 32 | 19 | 51 |
| Three third molars unerupted | 4 | - | 4 |
| Two third molars unerupted | 4 | 2 | 6 |
| One third molar unerupted | 1 | 3 | 4 |
| Upper right central incisor | 5(4) | - | 1 |
| Upper left central incisor | 3(1) | - | 2 |
| Upper right lateral incisor | 1(1) | - | - |
| Upper right first molar | - | 1(1) | - |
| Lower right first molar | 1(1) | - | - |
| Four second premolars unerupted | - | 1(1) | - |

Number in brackets denotes the number of subjects also represented in a third molar category.

TABLE 39(a). Number of subjects studied with one or more carious lesions (N = 50 males, 32 females).

| | Males | Females | Total |
|---|---|---|---|
| N | 23 | 8 | 31 |
| % | 46.0 | 25.0 | 37.8 |

TABLE 39(b). Number of carious lesions present in the subjects studied, according to surface of origin.

| | Males | Females | Total |
|---|---|---|---|
| Occlusal | 16 | 6 | 22 |
| Buccal | 38 | 15 | 53 |
| Lingual | 3 | - | 3 |
| Total | 57 | 21 | 78 |

TABLE 40. Number of amalgam restorations present in 50 males and 32 females, according to surface of location.

| Surface | Male | Female | Total |
|---|---|---|---|
| Occlusal | 3 | 2 | 5 |
| Buccal | 7 | 3 | 10 |
| Total | 10 | 5 | 15 |

TABLE 41. Number of subjects with evidence of moderate and severe dental fluorosis.

| Type of Fluorosis | Male | Female | Total |
|---|---|---|---|
| Moderate | 14 | 4 | 18 |
| Severe | 18 | 3 | 21 |
| Total | 32 | 7 | 39 |

TABLE 42. Mean values for the degree of attrition of Maxillary and Mandibular first molar teeth of 44 male and 28 female Australian Aborigines after the method of Davies and Pedersen ('55).

| | Subjects | Attrition Index (Mean) |
|---|---|---|
| Males | 44 | 1.44 |
| Females | 28 | 1.28 |

APPENDIX B

FORM 7

DENTGRO PROJECT

SKELETAL MATURATION STUDY

△ [ | | | ]

DATA CARD 1

1 [ | | | ] Subject

5 [ ] Sex

6 [ | | | ] Sibship

11 [ | | | | ] Chron. Age

18 [ | | | | ] Skel. Age

24 [ ] Pisiform Presence

26 [ ] Hamate Stage 1 Stage 2

28 [ ] Sesamoid Presence

30 [ | | ] Sesamoid Diam.

78 [ 1 | | ] Card

(COLUMNS 1-22 same as data card 1)

DATA CARD 2

1 [ | | | ] Subject

5 [ ] Sex

6 [ | | | ] Sibship

11 [ | | | | ] Chron. Age

18 [ | | | | ] Skel. Age

23

| | | | | | |
|---|---|---|---|---|---|
| Stature | n - s | pm - sp | pg - ar | pg - go | ar - go |

53

| | | | | |
|---|---|---|---|---|
| n - gn | n - sp | id - gn | pr - id | pm - s |

78 [ 2 | | ] Card

# APPENDIX C

## OSSIFICATION EVENTS STUDIED

Appearance of pisiform

Hook of hamate-stages 1 and 2

Appearance of ulna metacarpophalangeal sesamoid of the thumb

## Reference Points and Lines used

### Reference points

ar - articulare

gn - gnathion

go - gonion

id - infradentale

n - nasion

pg - pogonion

pr - prosthion

pm - pterygomaxillare

s - sella

sp - spinal point

### Reference lines

NSP - nasion-sella line

NL - nasal line

ML - mandibular line

RL - ramus line

## VARIABLES USED IN CORRELATION ANALYSIS

Magnitude of Peak Velocity

Chronological Age at Peak Velocity

Skeletal Age at Peak Velocity

were determined for the following measurements:

Stature

| | |
|---|---|
| n-s | n-gn |
| pm-sp | n-sp |
| pg-ar | id-gn |
| pg-go | pr-id |
| ar-go | pm-s |

Chronological Age

Skeletal Age

were determined for the following ossification events:

| | |
|---|---|
| Pisiform | Sesamoid-stage 1 |
| Hamate-stage 1 | Sesamoid-stage 2 |
| Hamate - Stage 2 | Sesamoid-stage 3 |
| Sesamoid | |

Sesamoid Stage

was determined for the following events:

| | |
|---|---|
| Peak velocity in stature | Peak velocity in n-gn |
| Peak velocity in n-s | Peak velocity in n-sp |
| Peak velocity in pm-sp | Peak velocity in id-gn |
| Peak velocity in pg-ar | Peak velocity in pr-id |
| Peak velocity in pg-go | Peak velocity in pm-s |
| Peak velocity in ar-go | |

## DIFFERENCES BETWEEN CHRONOLOGIC AGES OF PAIRED EVENTS

Peak velocity in stature and:

pisiform, hamate-stage 1, hamate-stage 2, sesamoid, sesamoid-stage 1, sesamoid-stage 2, sesamoid-stage 3, peak velocity n-s, peak velocity pm-sp, peak velocity pg-ar, peak velocity pg-go, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Pisiform ossification and:

hamate-stage 1 ossification, hamate-stage 2 ossification, sesamoid ossification, sesamoid-stage 1 ossification, sesamoid-stage 2 ossification, peak velocity n-s, peak velocity pm-sp, peak velocity pg-ar, peak velocity pg-go, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Hamate-stage 1 ossification and:

hamate-stage 2 ossification, sesamoid ossification, sesamoid-stage 1 ossification, sesamoid-stage 2 ossification, sesamoid-stage 3 ossification, peak velocity n-s, peak velocity pm-sp, peak velocity pg-ar, peak velocity pg-go, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Hamate-stage 2 ossification and:

sesamoid ossification, sesamoid-stage 1 ossification, sesamoid-stage 2 ossification, sesamoid-stage 3 ossification, peak velocity n-s, peak velocity pm-sp, peak velocity pg-ar, peak velocity pg-gp, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Sesamoid ossification and:

sesamoid-stage 1 ossification, sesamoid-stage 2 ossification, sesamoid-stage 3 ossification, peak velocity n-s, peak velocity pm-sp, peak velocity pg-ar, peak velocity pg-go, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Sesamoid-stage 1 ossification and:

sesamoid-stage 2 ossification, sesamoid-stage 3 ossification, peak velocity n-s, peak velocity pm-sp, peak velocity pg-ar, peak velocity pg-go, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Sesamoid-stage 2 ossification and:

sesamoid-stage 3 ossification, peak velocity n-s, peak velocity pm-sp, peak velocity pg-ar, peak velocity pg-go, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Sesamoid-stage 3 ossification and:

peak velocity n-s, peak velocity pm-sp, peak velocity pg-ar, peak velocity pg-go, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Peak velocity n-s and:

peak velocity pm-sp, peak velocity pg-ar, peak velocity pg-go, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Peak velocity pm-sp and:

peak velocity pg-ar, peak velocity pg-go, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Peak velocity pg-ar and:

peak velocity pg-go, peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Peak velocity pg-go and:

peak velocity ar-go, peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Peak velocity ar-go and:

peak velocity n-gn, peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Peak velocity n-gn and:

peak velocity n-sp, peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Peak velocity n-sp and:

peak velocity id-gn, peak velocity pr-id, peak velocity pm-s.

Peak velocity id-gn and:

peak velocity pr-id, peak velocity pm-s.

Peak velocity pr-id and:

peak velocity pm-s.

# APPENDIX D.

Computer output for growth velocities (on next page)

GROWTH ANALYSIS - SUBJECT 322 (FEMALE) PROGRAM GRAVES

| TRIP | C-AGE | S-AGE | STAT. | N-S | PN-SP | PG-AR | PG-GO | AR-GO | N-GN | N-SP | ID-GN | PR-ID | PN-S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AJ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| AL | 9.17 | 8.42 | 134.10 | 67.72 | 51.69 | 99.70 | 70.66 | 40.52 | 109.40 | 44.80 | 30.48 | 23.66 | 41.54 |
| AP | 10.95 | 10.50 | 143.50 | 68.54 | 53.28 | 102.30 | 74.32 | 39.80 | 111.60 | 50.00 | 31.30 | 21.52 | 42.70 |
| AQ | 11.95 | 11.00 | 151.80 | 69.12 | 53.34 | 106.00 | 76.08 | 42.06 | 114.40 | 50.50 | 31.38 | 22.04 | 45.20 |
| AS | 12.95 | 13.00 | 159.40 | 70.16 | 55.36 | 109.10 | 79.52 | 43.22 | 118.00 | 49.80 | 32.24 | 23.32 | 48.32 |
| AU | 13.95 | 13.50 | 165.80 | 70.78 | 56.98 | 110.90 | 82.18 | 44.04 | 120.70 | 49.04 | 33.56 | 22.46 | 48.03 |
| AV | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| AW | 15.95 | -0.00 | 168.10 | 71.58 | 58.92 | 113.50 | 84.60 | 44.68 | 122.90 | 56.32 | 34.63 | 22.42 | 49.03 |
| AY | 16.95 | 17.00 | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 | -0.00 | 53.80 | -0.00 | -0.00 | -0.00 |

ANALYSES FOR VARIABLE STAT. SUBJECT 322

| TRIPS | AGE LIMITS | | VELOCITY/YR | INTERVAL | MID-POINT |
|---|---|---|---|---|---|
| AL AP | 9.170 | 10.950 | 5.281 | 1.780 | 10.060 |
| AP AQ | 10.950 | 11.950 | 8.300 | 1.000 | 11.450 |
| AQ AS | 11.950 | 12.950 | 7.600 | 1.000 | 12.450 |
| AS AU | 12.950 | 13.950 | 6.400 | 1.000 | 13.450 |
| AU AW | 13.950 | 15.950 | 1.150 | 2.000 | 14.950 |

MAXIMUM VELOCITY 8.300
AGE LIMITS 10.950 AND 11.950
MID-POINT OF YEAR 11.450
SKELETAL AGE LIMITS 10.500 AND 11.000
MID-POINT OF SKELETAL AGE 10.750

ANALYSES FOR VARIABLE N-S SUBJECT 322

| TRIPS | AGE LIMITS | | VELOCITY/YR | INTERVAL | MID-POINT |
|---|---|---|---|---|---|
| AL AP | 9.170 | 10.950 | .461 | 1.780 | 10.060 |
| AP AQ | 10.950 | 11.950 | .580 | 1.000 | 11.450 |
| AQ AS | 11.950 | 12.950 | 1.040 | 1.000 | 12.450 |
| AS AU | 12.950 | 13.950 | .620 | 1.000 | 13.450 |
| AU AW | 13.950 | 15.950 | .400 | 2.000 | 14.950 |

MAXIMUM VELOCITY 1.040
AGE LIMITS 11.950 AND 12.950
MID-POINT OF YEAR 12.450
SKELETAL AGE LIMITS 11.000 AND 13.000
MID-POINT OF SKELETAL AGE 12.000

ANALYSES FOR VARIABLE ID-GN SUBJECT 322

| TRIPS | AGE LIMITS | | VELOCITY/YR | INTERVAL | MID-POINT |
|---|---|---|---|---|---|
| AL AP | 9.170 | 10.950 | .461 | 1.780 | 10.060 |
| AP AQ | 10.950 | 11.950 | .080 | 1.000 | 11.450 |
| AQ AS | 11.950 | 12.950 | .860 | 1.000 | 12.450 |
| AS AU | 12.950 | 13.950 | 1.320 | 1.000 | 13.450 |
| AU AW | 13.950 | 15.950 | .535 | 2.000 | 14.950 |

MAXIMUM VELOCITY 1.320
AGE LIMITS 12.950 AND 13.950
MID-POINT OF YEAR 13.450
SKELETAL AGE LIMITS 13.000 AND 13.500
MID-POINT OF SKELETAL AGE 13.250

ANALYSES FOR VARIABLE PR-ID SUBJECT 322

| TRIPS | AGE LIMITS | | VELOCITY/YR | INTERVAL | MID-POINT |
|---|---|---|---|---|---|
| AL AP | 9.170 | 10.950 | -1.202 | 1.780 | 10.060 |
| AP AQ | 10.950 | 11.950 | .520 | 1.000 | 11.450 |
| AQ AS | 11.950 | 12.950 | 1.280 | 1.000 | 12.450 |
| AS AU | 12.950 | 13.950 | -.860 | 1.000 | 13.450 |
| AU AW | 13.950 | 15.950 | -.020 | 2.000 | 14.950 |

MAXIMUM VELOCITY 1.280
AGE LIMITS 11.950 AND 12.950
MID-POINT OF YEAR 12.450
SKELETAL AGE LIMITS 11.000 AND 13.000
MID-POINT OF SKELETAL AGE 12.000

ANALYSES FOR VARIABLE PN-SP SUBJECT 322

| TRIPS | AGE LIMITS | | VELOCITY/YR | INTERVAL | MID-POINT |
|---|---|---|---|---|---|
| AL AP | 9.170 | 10.950 | .893 | 1.780 | 10.060 |
| AP AQ | 10.950 | 11.950 | .060 | 1.000 | 11.450 |
| AQ AS | 11.950 | 12.950 | 2.020 | 1.000 | 12.450 |
| AS AU | 12.950 | 13.950 | 1.620 | 1.000 | 13.450 |
| AU AW | 13.950 | 15.950 | .970 | 2.000 | 14.950 |

MAXIMUM VELOCITY 2.020
AGE LIMITS 11.950 AND 12.950
MID-POINT OF YEAR 12.450
SKELETAL AGE LIMITS 11.000 AND 13.000
MID-POINT OF SKELETAL AGE 12.000

ANALYSES FOR VARIABLE PG-AR SUBJECT 322

| TRIPS | AGE LIMITS | | VELOCITY/YR | INTERVAL | MID-POINT |
|---|---|---|---|---|---|
| AL AP | 9.170 | 10.950 | 1.461 | 1.780 | 10.060 |
| AP AQ | 10.950 | 11.950 | 3.700 | 1.000 | 11.450 |
| AQ AS | 11.950 | 12.950 | 3.100 | 1.000 | 12.450 |
| AS AU | 12.950 | 13.950 | 1.800 | 1.000 | 13.450 |
| AU AW | 13.950 | 15.950 | 1.300 | 2.000 | 14.950 |

MAXIMUM VELOCITY 3.700
AGE LIMITS 10.950 AND 11.950
MID-POINT OF YEAR 11.450
SKELETAL AGE LIMITS 10.500 AND 11.000
MID-POINT OF SKELETAL AGE 10.750

ANALYSES FOR VARIABLE PG-GO SUBJECT 322

| TRIPS | AGE LIMITS | | VELOCITY/YR | INTERVAL | MID-POINT |
|---|---|---|---|---|---|
| AL AP | 9.170 | 10.950 | 2.056 | 1.780 | 10.060 |
| AP AQ | 10.950 | 11.950 | 1.760 | 1.000 | 11.450 |
| AQ AS | 11.950 | 12.950 | 3.440 | 1.000 | 12.450 |
| AS AU | 12.950 | 13.950 | 2.660 | 1.000 | 13.450 |
| AU AW | 13.950 | 15.950 | 1.210 | 2.000 | 14.950 |

MAXIMUM VELOCITY 3.440
AGE LIMITS 11.950 AND 12.950
MID-POINT OF YEAR 12.450
SKELETAL AGE LIMITS 11.000 AND 13.000
MID-POINT OF SKELETAL AGE 12.000

ANALYSES FOR VARIABLE AR-GO SUBJECT 322

| TRIPS | AGE LIMITS | | VELOCITY/YR | INTERVAL | MID-POINT |
|---|---|---|---|---|---|
| AL AP | 9.170 | 10.950 | -.404 | 1.780 | 10.060 |
| AP AQ | 10.950 | 11.950 | 2.260 | 1.000 | 11.450 |
| AQ AS | 11.950 | 12.950 | 1.160 | 1.000 | 12.450 |
| AS AU | 12.950 | 13.950 | .820 | 1.000 | 13.450 |
| AU AW | 13.950 | 15.950 | .320 | 2.000 | 14.950 |

MAXIMUM VELOCITY 2.260
AGE LIMITS 10.950 AND 11.950
MID-POINT OF YEAR 11.450
SKELETAL AGE LIMITS 10.500 AND 11.000
MID-POINT OF SKELETAL AGE 10.750

ANALYSES FOR VARIABLE N-GN SUBJECT 322

| TRIPS | AGE LIMITS | | VELOCITY/YR | INTERVAL | MID-POINT |
|---|---|---|---|---|---|
| AL AP | 9.170 | 10.950 | 1.236 | 1.780 | 10.060 |
| AP AQ | 10.950 | 11.950 | 2.800 | 1.000 | 11.450 |
| AQ AS | 11.950 | 12.950 | 3.600 | 1.000 | 12.450 |
| AS AU | 12.950 | 13.950 | 2.700 | 1.000 | 13.450 |
| AU AW | 13.950 | 15.950 | 1.100 | 2.000 | 14.950 |

MAXIMUM VELOCITY 3.600
AGE LIMITS 11.950 AND 12.950
MID-POINT OF YEAR 12.450
SKELETAL AGE LIMITS 11.000 AND 13.000
MID-POINT OF SKELETAL AGE 12.000

ANALYSES FOR VARIABLE N-SP SUBJECT 322

| TRIPS | AGE LIMITS | | VELOCITY/YR | INTERVAL | MID-POINT |
|---|---|---|---|---|---|
| AL AP | 9.170 | 10.950 | 2.921 | 1.780 | 10.060 |
| AP AQ | 10.950 | 11.950 | .500 | 1.000 | 11.450 |
| AQ AS | 11.950 | 12.950 | -1.000 | 1.000 | 12.450 |
| AS AU | 12.950 | 13.950 | -.460 | 1.000 | 13.450 |
| AU AW | 13.950 | 15.950 | 3.640 | 2.000 | 14.950 |
| AW AY | 15.950 | 16.950 | -2.520 | 1.000 | 16.450 |

MAXIMUM VELOCITY 3.640
AGE LIMITS 13.950 AND 15.950
MID-POINT OF YEAR 14.950
SKELETAL AGE LIMITS 13.500 AND -0.000
MID-POINT OF SKELETAL AGE 6.750

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